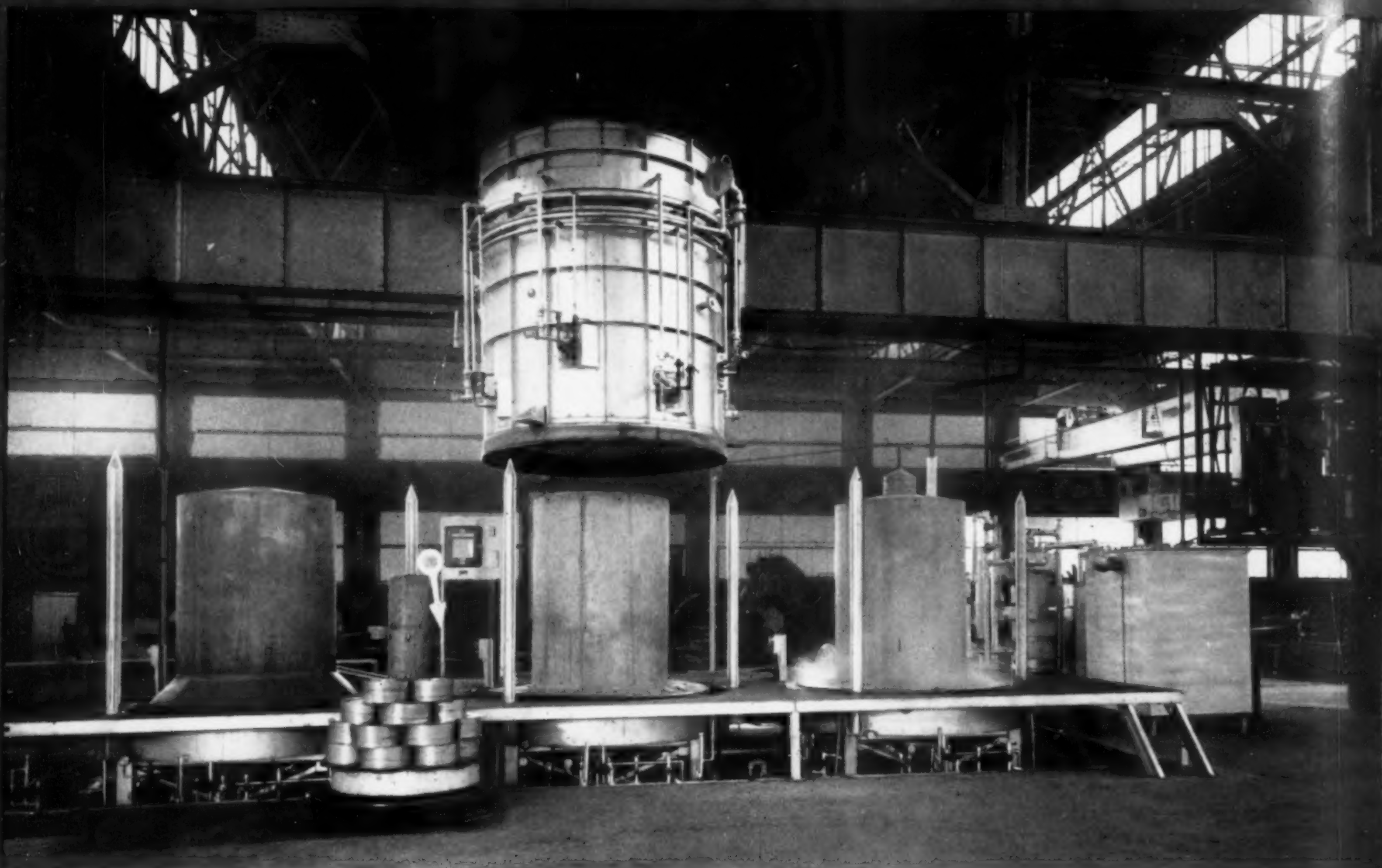
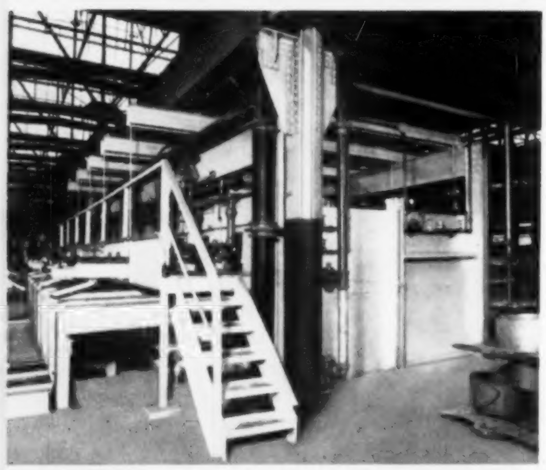
METAL PROGRESS

NOVEMBER ★ 1940

THESE NEW SC COPPER AND BRASS FURNACES ASSURE ACCURATE GRAIN SIZE CONTROL





● In the annealing of copper and brass strip for deep drawing it is essential that the grain size be controlled very closely. Especially is this true of the finish anneal since no subsequent rolling and equalization of grain size takes place. In the direct-fired, controlled atmosphere, bell type furnace (shown above) for bright annealing copper and clean annealing brass, a series of 27 consecutive heats ranging from 850° F. to 1150° F. showed a maximum variation in grain size of only ± .0025 millimeters between top, center, and bottom coils of the individual heats. Only five heats showed this maximum variation; ten heats showed no variation at all and the remainder less than ± .0025 mm. Tests of the recirculated air furnaces (lower left) showed similar uniformity of grain size.

On the breakdown anneal, control of grain size has facilitated rolling. In the new SC slab heating furnace (upper left) with automatic loading table and automatic discharge, slabs are conveyed through the furnace by a walking-beam conveyor mechanism and heated only one high to assure uniform heating and grain size. Write for additional information.

SURFACE COMBUSTION CORPORATION, TOLEDO, OHIO.

SURFACE SC COMBUSTION

WHEREVER HEAT IS USED IN INDUSTRY

Metal Progress

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Nov., 1940 Vol. 38 No. 5

Table of Contents

Cover is from a charcoal drawing by Earl J. Neff

Plastic Deformation in Metals .. 659
by S. L. Hoyt

Powder Metallurgy; Old and New Vistas .. 665
Reported by John Wulff

Critical Points .. 669
Notes on the Big Metal Congress
Supplies of Manganese and Tin
Centers of Technical Interest
Welders Go to Town
De-Hydrogenizers to Protect Alloy Steel From Flakes
Tube Welded Endlessly From Strip

Oscar E. Harder .. 672
A Biographical Note by H. Kenneth Briggs

Metallographic Preparation of Copper-Lead Bearings .. 674
by H. L. Grange

The Precipitation Reaction in Solid Metal Systems .. 677
by Martin Seyt

Covered Electrodes for Arc Welding .. 679
by Louis J. Larson

Temperature Conversions .. 683
Data Sheet

Commercial Aspects of Hardenability Tests .. 685
by Walter E. Jominy

Hot and Cold Heading .. 691
by A. S. Jameson

Deep Drawing Tests for Sheet Metal .. 698
by H. W. Swift; abstract of article in *Journal*, British Institution of Automobile Engineers, May 1940, page 361

Personal News, Largely Movements of A.S.M. Members .. 702, 704, 706

Biographical Notes and Portraits of Contributors .. 716

Literature Produced by Advertisers, Free to Readers .. 633-635

Index of Firms Which Are Advertising .. 740

Plastic Deformation *in* Metals

By S. L. HOYT
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Columbus, Ohio

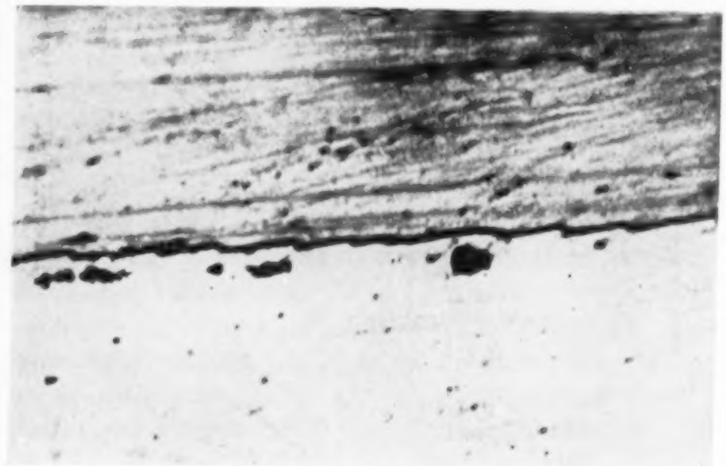
IN THE OPENING PART OF HIS CAMPBELL Memorial Lecture "The Scientific Method in Metallurgy" Doctor HOYT contrasted the philosophy of the natural sciences of Aristotle, which dominated the thought of the Western World for over 1500 years, years of barren scientific history, with the truly scientific method founded by Galileo. Formerly the teacher relied solely on his ability to make sound assumptions and on his facile technique of deductive reasoning. Galileo held that the natural sciences must be studied by observation and controlled experimentation, and that both assumptions and conclusions are to be subjected to experimental verification. Thus he placed the correct weight on the *validity of the premises.*

"The significance of Galileo's innovation becomes clear when it is recalled that except for this one point, alchemy made use of precisely the same processes and by perfectly logical reasoning produced a well rounded out branch of 'science'. In fact the phlogiston theory 'explained' the processes of oxidation and reduction and was accredited a high degree of plausibility when the predictions of theory were actually verified by experiment. The fallacy of this alchemistic doctrine was shown by BLACK'S epoch-making experiments which had as their objective, not the correctness of the reasoning, but the correctness of the basic assumptions. What alchemy provided was simply a mnemonic device, and the fallacy of the whole Aristotelian system lay with the failure to verify assumptions."

Doctor HOYT then cited the early chemical work that led to the atomic hypothesis of DALTON, the periodic classification of MENDELÉEFF. This was a forerunner of a great mass of controlled quantitative experimentation (which ultimately became physical chemistry and thermodynamics) and the recognition of energy as an attribute of matter — a concept utterly beyond the reach of Aristotelian methods. Finally GIBBS, by a prodigious feat of abstract reasoning, simplified and codified the conditions of equilibrium in all multiphase systems in the phase rule. After about 20 years this work became broadly available to research men, and at about the turn of the century was applied to metallic alloys by ROOZEBOOM. The lecturer traced the development of metallurgy up to that time and cited the development of equilibrium diagrams as a good example of the scientific method in metallurgy, where masses of experimental data are systematized by reference to underlying principles, and the underlying principles themselves are subjected to intense scrutiny.

Passing on to the question of atomic arrangements in solid metals, Doctor HOYT briefly outlined the evidence for our present concepts of crystalline structure of metals, solid solutions and intermetallic compounds. From here on the words are from his original text....

It is hoped that this hasty sketch of crystal structure and of the newer concepts of the metallic compounds will indicate the important advances which have recently been made. Speculation on these matters was not able to accomplish as much in 20 centuries as have the methods of X-ray crystal analysis in 20 years. The Greeks, we may note, could scarcely be expected to make any useful contribution with their "atomic theory", even with their unparalleled facility in the process of reasoning. In recent times even with the atomic theory of Dalton, the theory of space groups, and the valency theory of chemical combination, no general conception of structure or of chemical combination was forthcoming. This triumph of the scientific method is, in a sense, a fitting introduction to the problem of plastic deformation,



Section Through Electroplated Piece of Iron, Which Had Been Previously Polished and Strained, Showing Minute Slip-Band Steps About 0.00002 In. Magnification 1200 diameters. (*Rosenhain*)

This simple picture has survived throughout the intervening years and, with the assistance of models of deformed single crystals, it has become implanted in the minds of many as *the* mechanism of slip. Of course the picture we have in mind of this process must be tremendously important to a theory and while I do not suggest that ROSENHAIN's picture is incorrect, it is assuredly not the only one and I shall point out later that a fundamentally different and more general mode of deformation has received too little attention, commensurate with its importance.

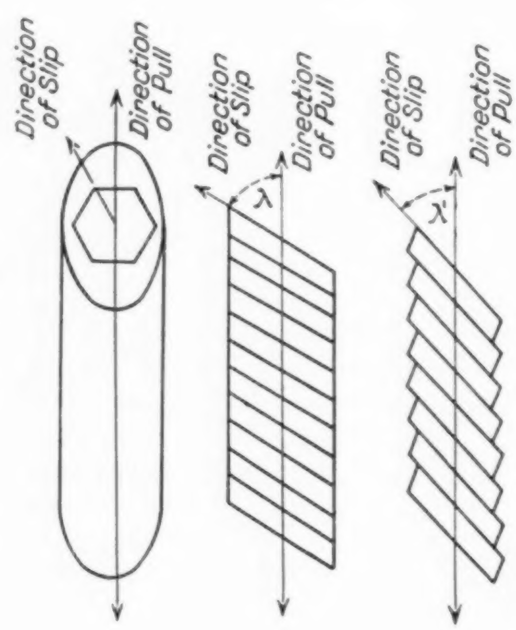
In the meantime the searching methods of X-ray crystal analysis have been applied to the problem, and test pieces in single crystal form have been used. As a result considerable information is now available on the stress-strain relationships and on planes and directions of slip. Actually the data have piled up like logs in a jam and the present situation corresponds to that in metallurgy at the time ROOZEBOOM clarified the constitution of alloys. The king log, in terms of an adequate theory of the metallic state, has not been found and we do not yet know how to classify and order the data or how to interpret them in terms of general laws.

By this I mean particularly that the precise atomic mechanisms of plastic deformation and strain hardening are not understood. Nevertheless many competent scientists have tackled these problems and it is significant that the metallurgist has given way to the physicist and the metallurgical physicist. Our principal fear as metallurgists is, I believe, that we may not be capable of following the reasoning or of grasping the significance of the results, though we may trust that some intermediary will arise to give us a simplified version of the theory. Consequently it

for it is in this same way that our ideas of that process should be built.

In establishing a theory of plastic deformation the first point to be settled is the precise mechanism of the movement or displacement of metal, yet it appears that too little attention has been paid to this point in recent years. EWING and ROSENHAIN found, among several possibilities, that metals behave as though made up of a large number of minute blocks and that during deformation these blocks slip over one another in response to the applied stress. This sliding action did not sever the bonds between the blocks and after deformation the metal was apparently as sound as before.

Directly following this original work ROSENHAIN applied a skillful technique to a further study of this problem. By protecting the surface of a sample which showed slip bands by coating it electrolytically with copper, and then sectioning it, he demonstrated the serrated "edge effect" that would be expected from the simple block movement just described. He also secured evidence of non-distortion of the blocks by showing that the same blocks, photographed before and after an increment of slip, showed no stereoscopic effect. His picture was simply that of a deck of cards with the edge of one card extending slightly beyond its neighbor.

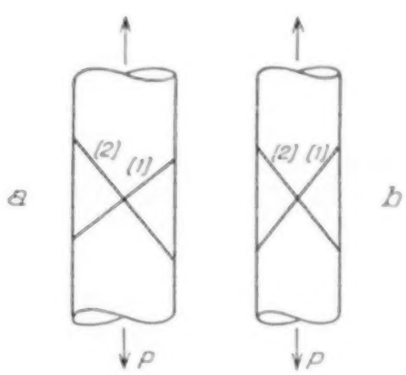


Representation of Direction of Slip in the Basal Plane of a Zinc Single Crystal. (*Elam*)

is with considerable diffidence that I venture to point out certain features that seem to require special attention.

It appears that a great need exists for close cooperation between metallurgists and physicists to develop a clear conception of just what it is that must be explained. Instead we find that one starts with one picture and another with a different one, yet each is covering the field and attempting to develop a general theory. The terminology also is highly confusing and various names are used to signify what is presumably one and the same thing. I would propose, as the first and highly desirable step, setting up a detailed and critical classification of the important phenomena. The object would be to bring everyone in agreement on what is and what is not known, and to suggest what is lacking and what points need special attention.

Let us take an example which comes from the work mentioned on single crystals, and which is selected because it bears on our picture of the movement during plastic deformation and on our understanding of the related phenomena.



At Left is Indicated the Initial Positions of Active (1) and Latent (2) Slip Planes in a Face-Centered Cubic Crystal. At right is the deformed crystal at the start of "double" slip

Single crystals of metals which have one slip plane, like the basal plane of the hexagonal close packed zinc, stretch out in tension as the slip planes tilt more and more into the direction of pull until rupture occurs. At the same time the slip planes rotate in their own planes as the direction of slip in the basal planes lines up with the direction of the major shear stress. This gives the simple elemental picture of the geometric behavior of the slip plane and slip direction under the action of an applied stress.

It becomes a little more complicated in metals whose structure permits slip on more than one plane. Thus the face-centered cubic metals have four sets of slip planes — the octahedral planes. If two of these four sets are symmetrical with the axis at the start, the crystal elongates by simultaneous slip on both sets, the details of which need not concern us here. If, however, the slip planes are oriented in some other way or at random, slip starts on only the one set which is most favorably oriented. The extension of the crystal tilts those planes and rotates them as was just described for zinc. Sooner or later, depending on the initial orientation, another set of octahedral planes must be brought into an orientation which is symmetrical with that of the "active" slip planes.

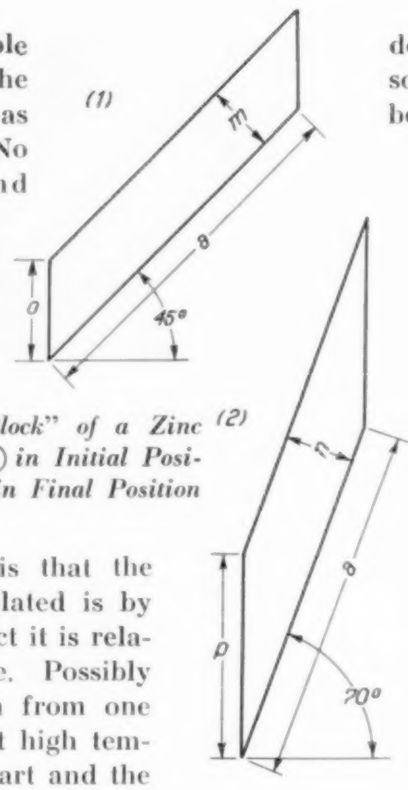
Let us see how that fits into the picture of simple block movement.

From the standpoint of mechanics the situation is the same as that for the initial orientation which has two sets of slip planes in symmetrical position — by which I mean that the resolved shear stress is the same on both sets of planes. Slip on the active planes has presumably strengthened them and we must argue that since no such movement has been going on on the second set, the latter must still be in a virgin condition and hence weaker than the first set. On this basis we would say that double slip would not occur at the symmetrical orientation, but at one for which the ratio of shear stress to resistance to slip is the same for both active and latent slip planes, with the proviso that the latent slip planes still preserve their initial low strength. This deduction follows from Rosenhain's simple picture of the deck-of-cards movement.

However, the situation is entirely different, for double slip starts when the second set of latent slip planes is approximately in the symmetrical position. Precise measurements show, in fact, that the latent slip planes which have supported no slip, in the usual sense, have been strengthened by some other though equally potent mechanism *even more* than were the active slip planes. This is a basic fact of plastic deformation and must be tremendously significant to those who attempt to develop a picture of plastic deformation. It is definitely inconsistent with a process which assumes no change whatever in the blocks proper, and which therefore cannot account for strengthening in directions or along planes which cut those blocks at an angle.

Direct observation also shows that metals deform and strengthen by a process which departs fundamentally from the deck-of-cards picture. This brings us to the pseudo-block movement which I described in 1926 for zinc crystals. As a part of the study there reported a number of critical tests for the serrated "edge effect" were entirely negative. Slip bands were

observed, it is true, but the visible blocks distorted approximately the same as the crystal did as a whole, as shown in the sketch alongside. No trace of serrated edge was found though it would have been clearly visible. While these observations have been discussed in great detail in the intervening years I know of no reason to doubt their correctness. Thus we have two general pictures of the slip process, both well supported.



Basal "Block" of a Zinc Crystal (1) in Initial Position; (2) in Final Position

My principal argument here is that the simple block movement first postulated is by no means the only one, and I suspect it is relatively the one of lesser importance. Possibly there may be a gradual transition from one type of movement to the other. At high temperatures the slip bands are far apart and the simple block movement is clearly in evidence; at lower temperatures more and more slip bands form and they increase in number as slip proceeds. It seems likely that block distortion sets in at some intermediate stage.

The pseudo-block movement obviates the difficulties in attempting to understand observations of single crystal behavior on the basis of a deck-of-cards movement, and places much less significance on the visible slip bands either as the major seat of slip or as the source of the strengthening effect. This is saying that our usual methods of observing blocks and slip bands are not adequate to the task, an observation I pass on to the aforementioned metallurgical physicists. Furthermore, while the slip process appears to be one involving the planes of a crystal, we should not lose sight of the fact that the further the situation is studied the clearer it becomes that the slip *direction* is of primary importance, and the slip plane only of secondary importance.

It is not my purpose here to propose how the physical theory should be developed but rather to point out that these basic facts and purely objective observations should be used as a guide, and that in the work in this field the scientific approach had been neglected. As an example we may take the work of Taylor who has recently stated and criticized the principal ideas on the mechanics of plastic deformation from the physical viewpoint.

He points out that one idea assumes that deformation breaks up initially sound grains into fragments which become disoriented and thus make the progress of slip more difficult. Taylor held this not to be valid for metals which have several sets of slip planes, such as the face-centered cubic. By appropriate combinations of slip (which would come about automatically) deformation could take place without producing any geometrical inconsistencies at the boundaries between fragments and therefore without increasing the resistance to slip. This being so, the strengthening effect would be left unexplained.

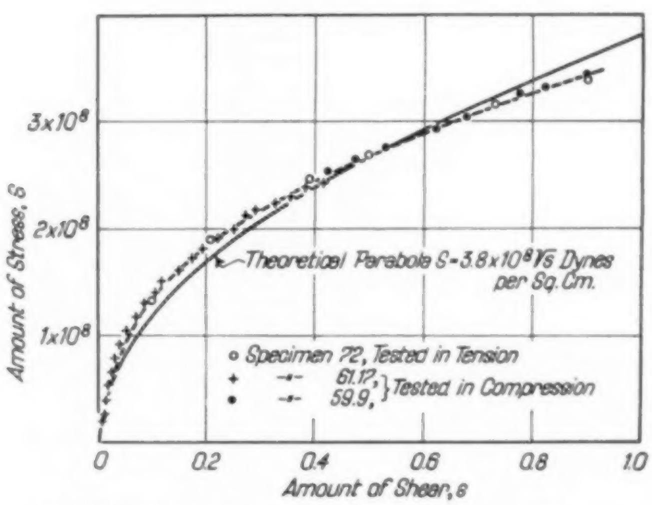
A second idea assumes that the metal crystal is initially a mosaic composite, the tiny constituent blocks being of slightly different orientations. It can be assumed that the interfaces carry the entire stress but this would not explain the increase of stress with strain. An alternate assumption might be that a block can support any stress system which does not have an effective stress component parallel to the slip planes, but this again would not hold for those metals which have more than one set of slip planes.

According to the third idea, to quote Taylor, "A perfect crystal is supposed to be capable of withstanding a very large stress. The observed weakness of metal crystals is attributed to concentrations of stress due to internal surfaces of misfit or cracks, and the increasing strength with increasing plastic strain is attributed to an increase in the number of faults or cracks. As the number of such faults increases the ratio of maximum stress in the region of stress concentration to mean stress in the material would be expected to decrease. The mean stress necessary to cause a given maximum stress in a region of stress concentration must, therefore, increase as the number of faults per unit volume of the material increases."

Taylor accepts this third idea as the basis of his own theory of "dislocations", which name he uses for the faults or cracks just mentioned. Upon the application of a load or shear stress above the yield point a dislocation is created

on one or more of the active slip planes which gives a local alteration of the positions of the atoms. The body of a block or fragment between two such slip planes supports the same shear stress as that at the interface, and it is a point of this postulate that the crystal is assumed to have a high natural strength. These dislocated atoms along the slip planes are the mechanical embodiment of stress concentrations. By making certain plausible assumptions covering the rate at which the flaws increase in number with deformation, the effects of boundaries, and the effectiveness of the flaws, the calculated stress-strain diagram agrees well with the experimental data. (See the curve just below.)

This appears to be a verified prediction, but Masing states that this coincidence is illusory. He points out that such stress concentrations at faults are capable of accounting for the Bauschinger effect (the alteration of the



Relationship (Theoretical and Experimental) Between Shear Stress S and Amount of Shear s for Three Aluminum Single-Crystal Specimens When Slipping in One Plane, According to Taylor

elastic limits by cyclic variations of stress), but not for an actual increase in the resistance to shear or true strengthening. The reason why a dislocation forms is not stated, but at this stage of the theory it is of no particular importance. It would be of greater immediate importance to show (which is not done) how the dislocation theory is to be reconciled with the basic facts of plastic deformation. Presumably Taylor is discussing dislocations on the visible slip planes but we are bound to ask, for example, by what mechanism the visible blocks deform, how block distortion is to be understood in view of the assumption of great natural strength of the blocks, and how it is that latent slip planes become strengthened.

It may be impossible to picture the atomic mechanism of slip in terms of a mechanical analogy but microscopic and X-ray work shows that the picture of block or fragment formation, in some form, does appear to be legitimate. While there is no proof of it as yet, these structure elements also behave as though relatively strong — which might mean that they ultimately form of such a small size that they support the applied stresses by simple elastic distortions. This is consistent with X-ray evidence but before a theory can be held to be adequate it must also answer the old question of why the atoms do not simply and spontaneously revert to their normal positions. Numerous facts of atom mobility suggest that the atoms should easily shift the slight amount required to produce straight rows or planes.

I have touched on the hardening or strengthening effect of plastic deformation in connection with the mechanism of the process for it has been so prominent in metallurgical discussions. In passing, I would point out that the metal is not necessarily made less malleable, and the ultimate theory of strengthening must be consistent with the retention of a deformation mechanism.

Shortly after the turn of the century Beilby postulated the formation of hard, amorphous metal along the slip planes of Ewing and Rosenhain, and it was asserted that this amorphous metal made slip more difficult and the metal stronger. This hypothesis was built up with such skill and argued with such persuasive logic that it dominated thought in this field for years. However, no tests were devised, at that time, by which the postulates could be either proved or disproved and the theory remained pure speculation. Amorphous metal was never shown to exist in the interior of metals, and its properties and characteristics were never under observation. On this account the amorphous metal hypothesis was always open to the eminently fair objection that it was absolutely unfounded, though in saying this it should be kept in mind that the question was not whether amorphous metal *could* form, but whether it *did* form.

Just as Black's tests proved the early phlogiston theory to be untenable, so have recent experiments shown the amorphous metal hypothesis to be invalid.

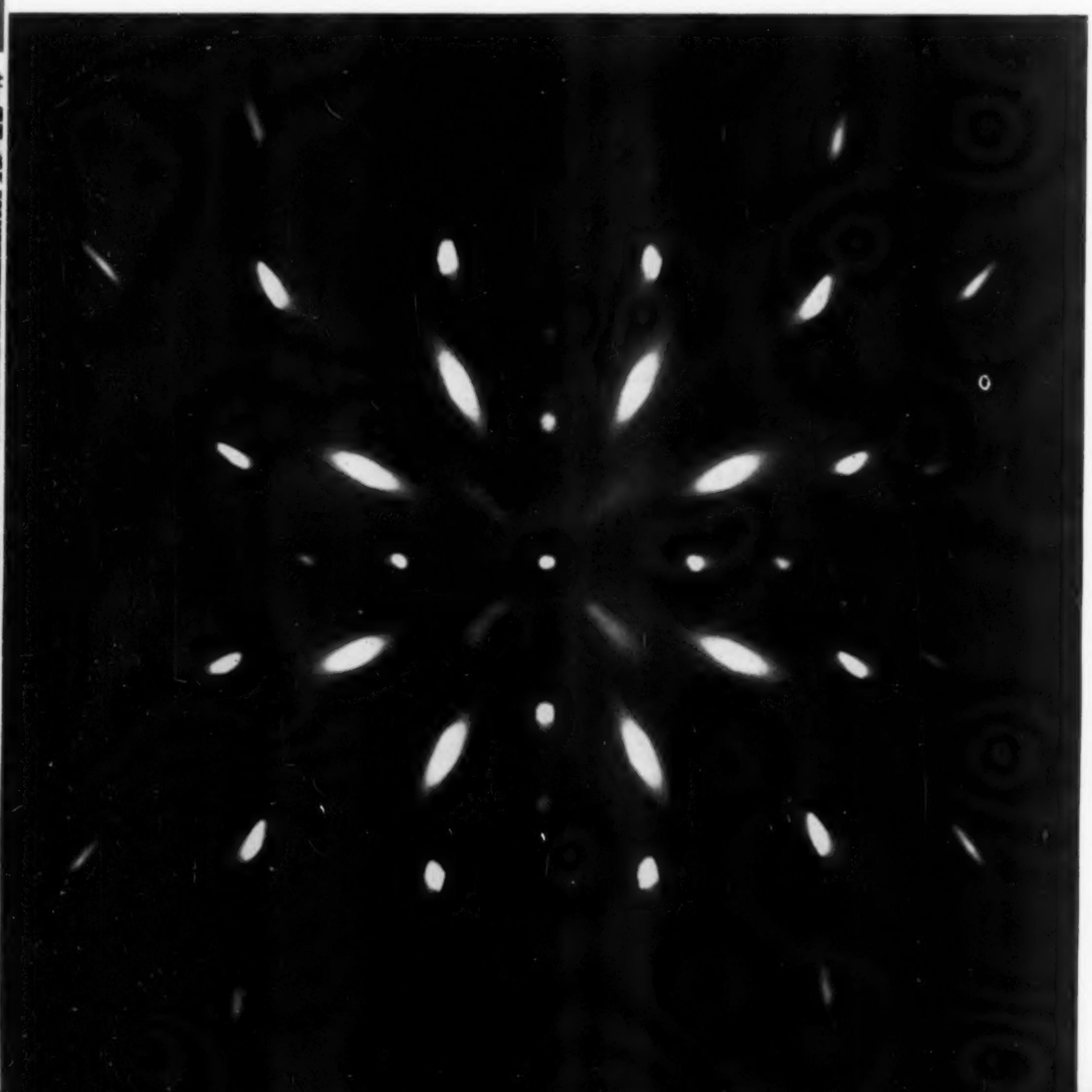
The first critical inspection was probably that of JEFFRIES and ARCHER who pointed out that the hypothesis was entirely inconsistent with the behavior of copper and tungsten when those metals were cold drawn by large amounts. However, soon thereafter a crucial test was provided by single crystal work that was particularly potent because it applied a fundamental principle of logic. For example, if it be hypothesized that it is raining outdoors, a simple inspection of the pavements may show that the hypothesis is incorrect. Wet pavements are a necessary consequence of rainfall. Of course evidence can be questioned, but the argument soon changes from one of rainfall to one of the condition of the pavement. A situation of this kind gives rise to a valuable crucial test.

In the present case we have to consider not the postulate of amorphous metal forming along slip planes but the validity of the single crystal evidence. In 1926 I drew attention to a certain behavior of zinc crystals which showed that amorphous metal does not form along the slip planes. As a crystal is being stretched in tension it is observed that the blocks of the central portion rotate spontaneously, due to a component of the principal shear stress. The slip planes are required by their structure to slip in the direction of an axis which, in general, is not in the direction of the principal shear stress. One component of this shear stress produces the slip while the other component, at right angles, acts as the force which lines up the slip planes with the direction of the principal shear stress.

According to BEILBY'S hypothesis the blocks would be separated by amorphous metal which had formed during slip and, by definition, would have no directional properties. Actually this rotation is uniquely crystallographic in nature and could not possibly be transmitted from the fixed ends of the crystal in the grips through intervening material having an isotropic or even quasi-isotropic structure.

Objections to BEILBY'S hypothesis have also been raised by CARPENTER and ROBINSON who comment: "As this hypothesis does not offer any explanation as to why the different planes which successively become involved in slip should offer a progressively increasing resistance to it, it does not explain this most important fact." The most direct evidence seems to me to be the point I advanced before this Society in 1936 in the symposium on plastic deformation. With BEILBY'S picture of strong blocks, it is the well verified finding that the latent slip planes of face-centered cubic metals, along which no slip has taken place, are strengthened even more than were the active slip planes, along which slip did take place. Obviously amorphous metal has nothing to do with this.

My object here is not to bury BEILBY'S hypothesis, but to point out that it, and other similarly founded metallurgical hypotheses, offer examples of a procedure that should be avoided in scientific work. *(Continued on page 732)*



Some of the Evidence Used by Students of the Metallic State. Laue photogram made in Metals Research Laboratory, Carnegie Institute of Technology, by Charles S. Barrett and A. H. Geisler. The sample is a single crystal of aluminum so set up that the X-ray penetrates it parallel to a cube axis. Four radial streaks near the central spot have been intently studied recently and shown by Preston in England and Zacharias in Chicago to be caused by the thermal vibrations of the atoms in the crystal. The higher the temperature the more intense they are, but they are clearly marked in this somewhat over-exposed photogram at 70° F.

Powder Metallurgy

Old *and* New

Vistas

Reported by
JOHN WULFF
Massachusetts Institute of Technology
Cambridge, Mass.

"POWDER METALLURGY — this new art of mixing powders, pressing and sintering the same into products that suffer a change into something wonderful" — so Bill Eisenman concludes after looking over many papers in the technical press.

Initiated and uninitiated, brought to the same judgment, are therefore forced to read patent literature for knowledge of this field, and at best patent literature is a lean diet. Hence some 150 persons came not without misgivings to the Powder Metallurgy Conference in late August at Massachusetts Institute of Technology. Among them were representatives of most of the groups engaged in powder metallurgy and its neighboring branches. In spite of the rather high attendance of the legally minded, all were agreeably surprised to see engineers and industrialists contributing freely to the community fund. By the second afternoon, everyone was in the proper frame of mind for F. V. Lenel of Moraine Products Division of General Motors, whose paper on "Oil Pump Gears, an Example of Iron Powder Metallurgy" gave the conference its focus.

Of the nineteen scheduled papers, the first ten gave an introduction to the subject and included modern data on metal powders — their manufacture, classification, specification, and application (H. E. Hall and D. O. Noel of Metals Disintegrating Co.); press and die design (Lawrence H. Bailey of Stokes Machine Co.); sintering methods and atmospheres (R. P. Koehring of Moraine Products and later H. M. Webber of General Electric); structural effect of pressing, repressing, and hot pressing (C. G. Goetzel of American Electro Metal Corp.); sintered carbides (P. M. McKenna of McKenna Metals Co.); and refractory metals (H. W. Highriter of Fansteel Metallurgical Corp.).

A sketchy view of the patents in the field by A. W. Deller, lecturer on patent law at Columbia, and a short and scholarly introductory paper on the early history of powder metallurgy by Cyril S. Smith of the American Brass Co., were other high lights of this group of papers. The patent talk naturally covered a great deal of ground and also contained some advice on the proper perusal of patents. Smith's paper and his own extensive experience probably led P. E. Weingart to remark, toward the end of the meeting: "It seems that powder metallurgy is an ancient and not too venerable art which is now experiencing the growing pains of second childhood."

The discussion in and about these papers led by Charles Hardy and later by C. Claus of the Bound Brook Bearing Co. was along the following lines:

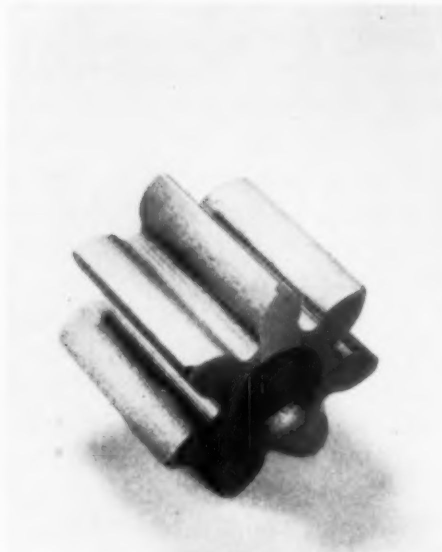
Though Wollaston in 1828 recognized the importance of powder quality, of press and die design, as well as of sintering methods, examples of powder metallurgy may be found in ancient Peru and India.

For many production purposes, straight hydraulic presses are too slow.

Asymmetric compacts can be pressed with the more plastic powders and usually with an admixture of from 0.25 to 1.0% of a solid lubricant, such as "stearotex".

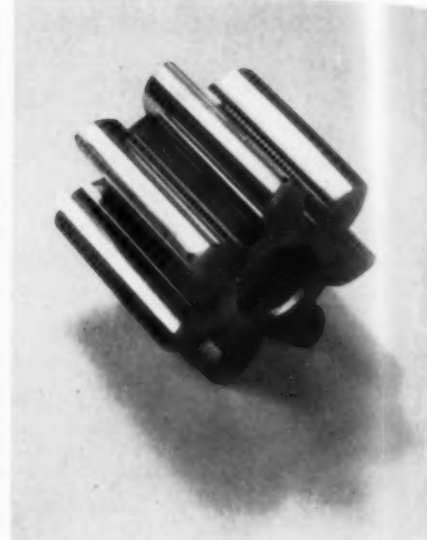
Accepted theory of die design may be employed successfully, but finishes and clearances need to be carefully held. J. Q. Adams (General Electric) mistrusted all caliper clearance measurements and suggested optical methods which permitted a survey of the complete die clearance when in position.

Although the crystal chemistry of



Impeller Gear
Machined From Cast Iron

Cast Iron Slug
for Gear at Left



Impeller Gear
Pressed From Powder

McKENNA's double carbides made from a molten aluminum or nickel menstruum was not too clear, the physical properties and service machining tests bear out the superior quality of such materials in high-speed cutting of some materials, including hardened steels.

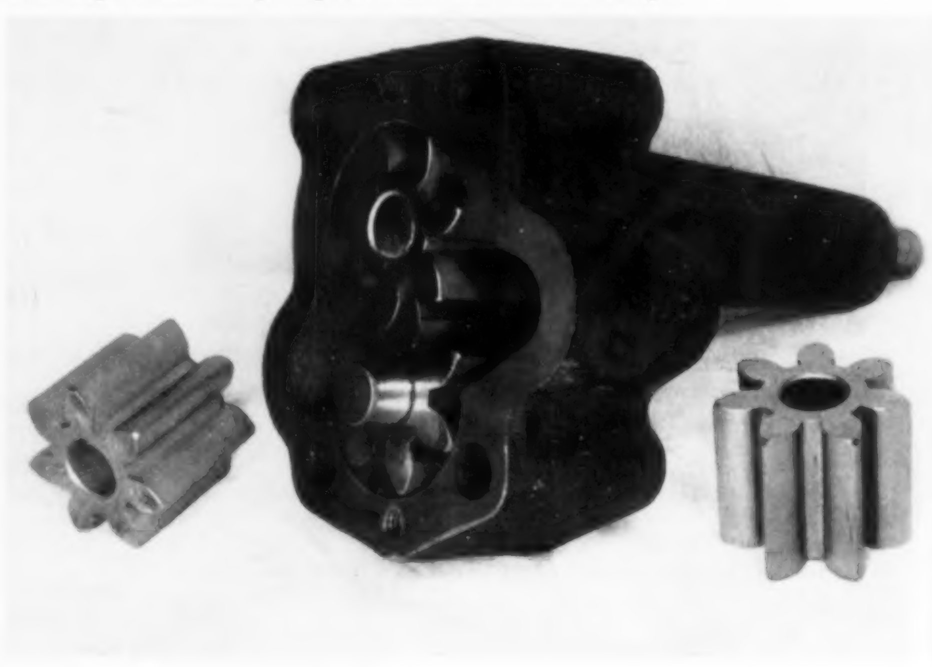
Simple pressing and low-temperature sintering may give special and useful properties to an object, but the usual products require repressing or hot pressing to achieve the higher density and mechanical strength necessary if they are to simulate the properties of cast and forged materials. This additional processing is economically feasible only for higher-priced articles, such as the refractory metals, contact materials, and cemented carbide tools.

As to what constitutes prior art in general and powder metallurgy in particular, we can tell you only after Mr. DELLER sends in his manuscript — until then we are still at sea with the semantics of the discussion.

G. H. HOWE's paper on "Development of Sintered Alnico", and F. R. HENZEL's on "The Physical Properties of Metal Compositions with a Refractory Metal Base", were good illustrations of the more advantageous applications of powder metallurgy. Some of the data presented in the former paper have been given elsewhere, yet many of the points were never before stressed so well for those untutored in the art of powder metallurgy.

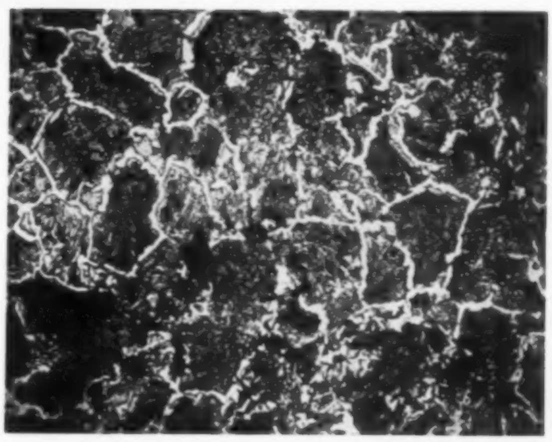
For example, commercial manufacture of small permanent magnets from mixtures of pure aluminum, nickel, iron and other powders is uneconomical principally because of the long sintering times and high temperatures required. To go to the other extreme — that of shotting and crushing of alnico melts and solids to a fine powder — this is also uneconomical not only because of the difficulty of pressing (which is dependent on the plasticity of the material), but also because of the inferior magnetic prop-

Small Oil Pump for Automobile Engine (Cover Removed)
Showing Placement of Impellers in Cast Iron Housing



erties thus obtained. Here partial instead of total pre-alloying is highly advantageous. The ferro-aluminum alloy made from pure component metals can easily be powdered; it does not, however, possess the plasticity of either of its components, yet it has an extremely thin oxide skin whose obstructing influence in sintering becomes noticeable only if the powder is heated in air above 1100° F. In spite of lack of plasticity in the ferro-aluminum powder, compression of the powder charge and ejection without cracking or crumbling are possible because of the plasticity of the admixed powders, notably nickel. Many of the matters reported in other papers, thanks to the chairman, GREGORY J. COMSTOCK (Stevens Institute of Technology), were again touched on in the discussion of this paper, and Mr. HOWE's replies gave an excellent perspective to a specialized job of which powder metallurgists and General Electric Co. can well be proud.

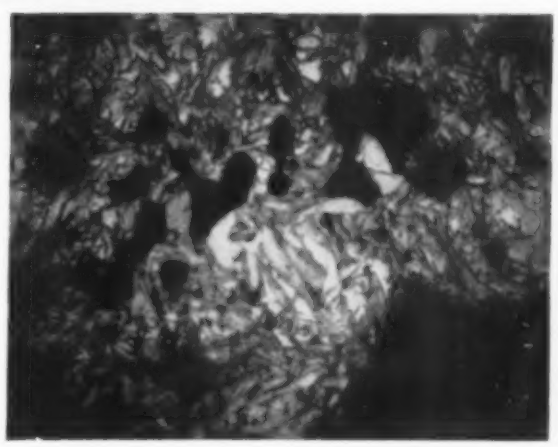
Top Left: Graphite and Iron Mixture After Sintering to Eutectoid Steel; Center: More Graphite Forms a Hyper-eutectoid Steel; Below: A High Carbon Cam (of Larger Porosity for Oil Absorption) Hardened to Martensite



Ferrous Powder Metallurgy

Products made from iron powders have been extensively produced this past year, but until now we have heard little about them. This condition applies as well to iron powder, on which many are working. Few can compete in quantity, quality, and price with the excellent plastic Swedish sponge iron powder. How long the supply will last is another matter. Domestic iron powders which are available in small quantities have usually one or more shortcomings. Aside from those already mentioned, these often include too much silica and carbon, as well as a structure which makes for die wear and difficulty of compression.

The oil pump gears illustrated in the accompanying engravings were made by the Moraine Products Division of General Motors and are in service in one of the 1940 model cars. E. V. LENEL's paper was restricted entirely to this example, yet its detail permits of greater generality; namely, that the technique employed can compete not only with machined cast iron previously used, but that, when porosity is not undesirable, the parts thus made are superior. The gears photographed on the opposite page were made from the so-called Swedish sponge iron. The powder all passes through a 100-mesh screen and, to insure free flowing and good compression characteristics, contains a minimum percentage of −325 mesh material. The iron is mixed with graphite powder, which serves as a lubricant in pressing and as a source of carbon in converting the compact into a steel or "cast iron" during sintering. As a compromise between tool wear and strength of ultimate compact, pressures of from 40,000 to 60,000 psi. are employed. The major die wear is limited to the vertical walls of the die barrel. As many as 30,000 gears of excellent micro- and macro-profile may be pressed in one such barrel if care is taken during the initial lapping of the die. The sintering time and temperature (20 to 40 min. at about 2000° F.) are also a compromise



between metallurgical factors (such as structure) and resulting strength and shrinkage.

The sintered gears as they emerge on the conveyor system from the cooling zone of the furnace (which, by the way, contains a partially burned natural gas atmosphere) are impregnated with oil; they have about 20% voids after sintering. Thereafter the inside diameter of the gears is burnished and broached, the outside diameter is ground, the end length is machined, and the teeth are chamfered. In each process only a few thousandths of an inch of material is removed, but this dimensioning is highly important to the efficient operation of the gear. The most vital surfaces of the gear, however, need not be finished, for they exhibit a better approach to a true involute profile for a sintered gear than do the cut cast-iron gears previously made, the latter deviating as much as 0.0013 in. from the theoretical line.

The photomicrographs exhibit a fine-grained structure, one which is typical of steel of about eutectoid composition, and a uniform distribution of voids. Further slides illustrated structures achieved by use of a different powder; these simulated hypereutectoid steels. In no case were the original powder particles discernible after sintering.

Goetzel and others pointed out that mechanical properties cited for these gears, such as tensile strengths of 20,000 to 25,000 psi., compressive strengths of 120,000 psi., and Rockwell hardnesses of B-30, must be considered extremely low. Lenel emphasized that these were comparable to the properties of the cast iron previously employed and that the new material has wear resistance equivalent to that of the cast iron, although the indentation hardness of all porous materials is notoriously low. Above all, the technique permits a better and cheaper gear.

To another representative of General Motors, A. L. Boegehold of the Research Laboratory Division for his paper on "Copper-Nickel-Lead Bearings", credit for the success of the meeting is also due. Besides stressing the fabrication and general metallurgical problems, Boegehold, in the short time allotted, was able to cover aspects of bearing wear, corrosion, and fatigue failures of great interest. Those acquainted with R. P. Koehring's article in the August issue of Metal Progress on the manufacture of this new steel-backed bearing will welcome the proposed publication of Boegehold's more metallurgical account of this development.

Manufacture of Powders

The Saturday morning session of the conference was handled with wit and dispatch by P. E. Weingart. J. D. Edwards of the Aluminum Co. of America, Henry Mandle of United States Bronze Powders, J. E. Drapeau, Jr., of Metals Refining, and M. F. Rogers of Callite Tungsten all emphasized the troubles encountered in the commercial production of powders and the need for refined techniques in determining the characteristics of powders for pigments as well as for compacting (briquetting) and sintering purposes.

During their presentation and in the questioning, Edwards and Mandle discussed "leafing" — that property of flake powder pigments which permits them to give maximum coverage and hiding power to an underlying surface. To achieve proper "leafing" flake the problems seem to be the orientation of the stearic acid on the extremely thin initially underlying oxide film, and the selection of the proper vehicle. Though little new data of scientific interest were presented, the importance of milling was again discussed. After questioning, Edwards touched on aspects of the aluminum powder therapy as an ameliorative and possible preventive of silicosis. Some in the audience, with and without ideas on a potential market for extremely fine aluminum powder, *(Continued on page 720)*

Properties of Aluminum Compacts

(All heated in air for 24 hr. and quenched in water.)

Mixture	Manufacturing Conditions		Properties of Compact		
	Consolidating Pressure Tons per Sq. In.	Sintering Temperature	Tensile Strength, Psi.	Density	Voids
90% Al + 10% Mg	20	800° F.	5,340	2.266	13.0%
	30	800	17,700	2.409	7.5
	55.7	800	24,900	2.519	3.3
90% Al + 10% Zn	40	700° F.	10,860		
	40	800	13,620		
	40	950	15,460		
90% Al + 7% Zn + 3% Mg	40	700° F.	21,400		
	40	800	32,900		
	40	950	40,000		

Critical Points

By THE EDITOR

AFTER A WEEK AT NATIONAL METAL Congress and Exposition, reduced to attempt a WALTER WINCHELL series of "flashes" . . . . . Efficiency of carburizer energizer is being studied, so as to hurry the pack hardening process and compete with the trend toward speedier methods . . . . . GIER of Westinghouse makes protective atmospheres low in CO_2 and H_2O by burning gas in limited air in a mass of catalyst . . . . . And tests its effect on steel by drawing it over a fine wire heated in a test tube (see METAL PROGRESS, October 1940, p. 566) . . . . . TOUR of Lucius Pitkin, Inc., vigorously disagrees with other authors in the same program in a refreshing change from our usually too-polite discussions . . . . . The multitude of precision gas burners of diverse design in Gas Association's combined industrial gas exhibit . . . . . The 9-ft. line of these in Surface Combustion's booth engulfing a copper wire with flame and delivering it properly annealed and absolutely bright to a cooling tube . . . . . Speakers' breakfast, A.I.M.E. luncheon, Industrial Welding Research dinner . . . . . Whose worries are to determine the carbon and manganese limits for plain steel to be easily weldable, and to find weldability tests for the alloy steels . . . . . Suggestion by PATTERSON of Solvay Process Co. to steel men looking for a quick test for silicon in iron from the mixer: Use a hydrometer with graphite stem and steel sinker, cheap and innocuous enough to leave in the molten iron after the test . . . . . U.S. Government buys the biggest bending press in the Show . . . . . A naval ordnance official comes to the Exposition to tell the malleable foundrymen that their product can be adopted for many uses on warships . . . . . FRANCES CLARK of Western Union says that microscopic measurement of voids in objects formed of powdered metal — as of electrical contactors — is not at all easy or accurate . . . . . Typewriter type molded of powdered metal and porous enough to pass liquid ink. No more ribbons . . . . . Precision control instruments, pyrometers and oscillographs attached to a lathe for testing machinability of metal in the U.S. Steel Corp. booth . . . . . MORRISON of Landis Machine Co. expounding his observations that high speed steel carburizes when preheated even in atmospheres high in CO (probably because a little soot deposits on the cool steel) yet these same atmospheres at the high heat decarburize and oxidize the steel simultaneously . . . . . Since the *surface* of toolsteel does the work, it is well that at last some attention is being given to the very outside of a tool . . . . . Mahr Mfg. Co. appears to have something of value for tool furnaces in its simple system for regulating both air-gas ratio and temperature simultaneously . . . . . HERZIG and associates (Climax Molybdenum Co.) give an "S" curve for a moly high speed showing austenite stable for two weeks (yes, two *weeks*) or more between 1100° and 700° F. Therefore hot straighten all such tools after quenching in molten lead . . . . . International Acetylene Association breakfast, Canadian members' luncheon, A.I.M.E. dinner where past president ALLEN said we now have enough manganese available in U.S.A. for 26 months of 100% steel production if all seas except the Cuban waters were closed to us tomorrow, and this could be extended 25% by parsimonious use . . . . . Tin — about a year's supply. Germany has developed substitute containers for tin cans, but recently decreed substitutes for the substitutes . . . . . "Corronized coatings" — 0.00003 in. of tin electroplated over 0.00003 in. of nickel on sheet steel and heat treated — as demonstrated by RIMBACH in Standard Steel Spring's exhibit — would save ⅔ of the tin on hot-dipped coating (or 5/6 if only one side were protected) . . . . . A performance of Hamlet without the Prince of Denmark when President GILL awards the Sauveur Achievement Medal . . . . . SAM HOYT breaks a precedent — or is it an unwritten law? — about the Campbell Memorial Lecture, and makes it philosophic and critical rather than factual . . . . . Past President and Founder Member WHITE, speaking as Colonel, Ordnance Dept., U.S.A. (reserve) tells the Cleveland Advertising Club luncheon some of the difficulties of expanding the inspection crew from 21 men to 33,000 during World War I . . . . . The overflow audience at the discussion on electrolytic polishing wherein the metallographers swapped information but the commercial men covered up . . . . . The beautiful micros of copper alloys in natural colors shown by BROWN

Notes on the Big Metal Congress

Supplies of Manganese and Tin

of W. S. Tyler Co. . . . . . Rustless Iron and Steel Corp. demonstrates the process on stainless steel wire and makes paper clips therefrom. It's a cinch on single phase or solid solution metals like stainless, but the alloy must be very clean. In fact, RUSSELL of Battelle Memorial Institute says 18-8 castings are electro-etched rather than electro-polished if they contain intergranular carbides . . . . . Contrasting comment heard in the elevator after one of GENSAMER's lectures on tri-axial stresses: "I'm beginning to see some light on this stuff!" vs. "This professor is clear over my head!" . . . . . The top cut of roast beef at Jones and Laughlin's buffet supper for editors and advertising men makes this the eatingest convention ever . . . . . Ampco Metals' centrifugal casting for a screw-down nut, big as a barrel . . . . . Two micro-hardness devices in adjoining booths: The well-engineered "Tukon" (KNOOP-PETERS indenter as outlined in "Critical Points", July 1939) in Wilson Mechanical Instrument's exhibit, and the EBERBACH device in Bausch & Lomb's which interchanges with the microscope objective a fixture containing an accurate spring and a tiny Vickers diamond . . . . . How different the looks of the metallographic microscopes and those shown in Chicago in 1919! . . . . . The straw vote in *Steel's* booth (using voting machines by Republic Steel's Berger Mfg. Division) showing 60% hard-shell Republicans, 20% third-term Democrats and 20% no-third-term Democrats — now just something to file and forget . . . . . The large sales of books and memberships in METAL PROGRESS's booth. (Memo: It pays to exhibit) . . . . . Stainless steel is still a very live subject; note the exodus of audience after the sigma phase was disposed of . . . . . Drever Co. demonstrates surface hardening of stainless steels and irons for seizure and wear resistance in a nitriding cycle: 36 hr. at 1050° F. in cracked plus anhydrous ammonia . . . . . Other centers of technical interest: Grain size, grain size measurement, hardenability . . . . . ROSHONG's lecture on quenching as it is done when you have to make some money on the business — a rare example of a practical talk for practitioners . . . . . The mechanized presentation (movie with narrator and sound effects) of SCHMIDT, GROSS and DELONG's discourse on surface treatments for magnesium alloys seems the answer to the eternal problems of lantern slides, mumbling speakers, and time limits . . . . . Chairman BATES' remark: "Now that presentation has been mechanized, perhaps something can be done about chairmen." . . . . . The platinum blonde in the information booth diverting attention from the ticker tape and Cyclones in Lindberg Engineering Co. booth just below . . . . . Also the bathing beauties photographed in Alcoa's aluminum sail boat, fully rigged, if you know what I mean . . . . . The growing use of advanced electrical equipment in heating, melting and hardening of metal, to say nothing of electron tubes in all sorts of measuring and control equipment . . . . . General JOHNSON's speech at the record-breaking banquet, wherefrom one gathers that he doesn't like Commander-in-Chief ROOSEVELT or his captains and thinks the defense program is stalled . . . . . General WESSON's speech at the Army Ordnance Asso. dinner, wherefrom one gathers that he has a high regard for General CROWELL and other colonels and majors, and is sure the defense program is coming along with amazing speed . . . . . Privates in the national effort can take their choice, if they need authority to back up their opinions derived from personal observations . . . . . National defense dominates newspaper publicity during the week, although exhibits were peaceful enough except for Republic Steel's showing of a White scout car. Here also was a simple and compact shotwelding machine making tiny airplanes . . . . . Silver soldering of small oven thermostats by the hundred thousand and jigs therefor as described by ZAPPONE of Robertshaw Thermostat Co. . . . . . Unionmelt — that amazing process for welding seams in thick plate — now adapted for spot, plug or rivet welds . . . . . Lakeside Steel Improvement's flame hardening equipment whose quenching stream steps on the heels of the heating flame . . . . . The surprising number and space occupied by exhibitors of welding supplies and the size of the flame-cutting equipment . . . . . The same remark applies to the cleaning machines by American Foundry Equipment and Pangborn Corp. . . . . . The delicacy of Clement Diamond Tool Co.'s plush-encased diamonds, the products of American Gas Furnace Co.'s glass blowers, and the nameplates and other colored ornamental metals made by Anderson & Sons . . . . . The effective use of animated figures and puppets, such as Bethlehem's model electric furnace, Tidewater Oil's two workmen, Macklin's grinding wheel operators, Allegheny Ludlum's drum majorette . . . . . The notable booth of Bridgeport Brass, entirely decorated with metal . . . . The size and strength of Phoenix-Lester's pressure die casting machine

Centers of Technical Interest

Welders Go to Town

. . . . . Prevalence of subdued colors indicates the trend away from the garish Chicago Century of Progress Exposition . . . . . For which surcease much thanks from this dizzy commentator who closes: "By all means come and see for yourself; you can't afford to miss it!"

Looking over some lecture notes from Milwaukee Chapter's educational course on forgings and pondering over the paradox in Adolph Schaefer's remarks about heavy forgings and ingots being the more tender to heat and handle the bigger they are, else serious internal checks will occur. (Schaefer is engineer of tests for The Midvale Co.) Seemingly the coarse crystalline ingots are most susceptible to a variously named defect, and as forging progresses and the grain is refined, the chance for their development diminishes. These defects being internal, a deep surface zone is immune, and when the thickness of forging or billet gets to the neighborhood of 3 in. it is all surface zone and danger should be gone — but not entirely, if we class rail fissures as coming from this same source. Hydrogen gas is currently regarded as the culprit. While much of it comes out of solution or combination in the iron rather suddenly upon solidification, a lot more appears at about 575° F. when the steel is in a brittle range, and unless cooling is very slow so the gas can safely diffuse out, its pressure accumulates until it makes a small check or crack in the steel. Rumor is that alloy steel makers have their secret "de-hydrogenizers"; some are exceedingly potent protectors of such tender steels as chrome-nickel-molybdenum billets from the electric furnace. Francis Foley, superintendent of research of The Midvale Co., tells me that one sure way to avoid "flakes" is to use nothing but well-made acid openhearth steel for big forgings. He is not so sure that hydrogen is the entire cause of flakes, nor that they always form at moderate temperatures, but if they are due to hydrogen the susceptibility of basic openhearth steel (when an acid steel of the same composition is immune) may be due to the generous use of lime as a slag-making base, and lime is a regular sponge for moisture.

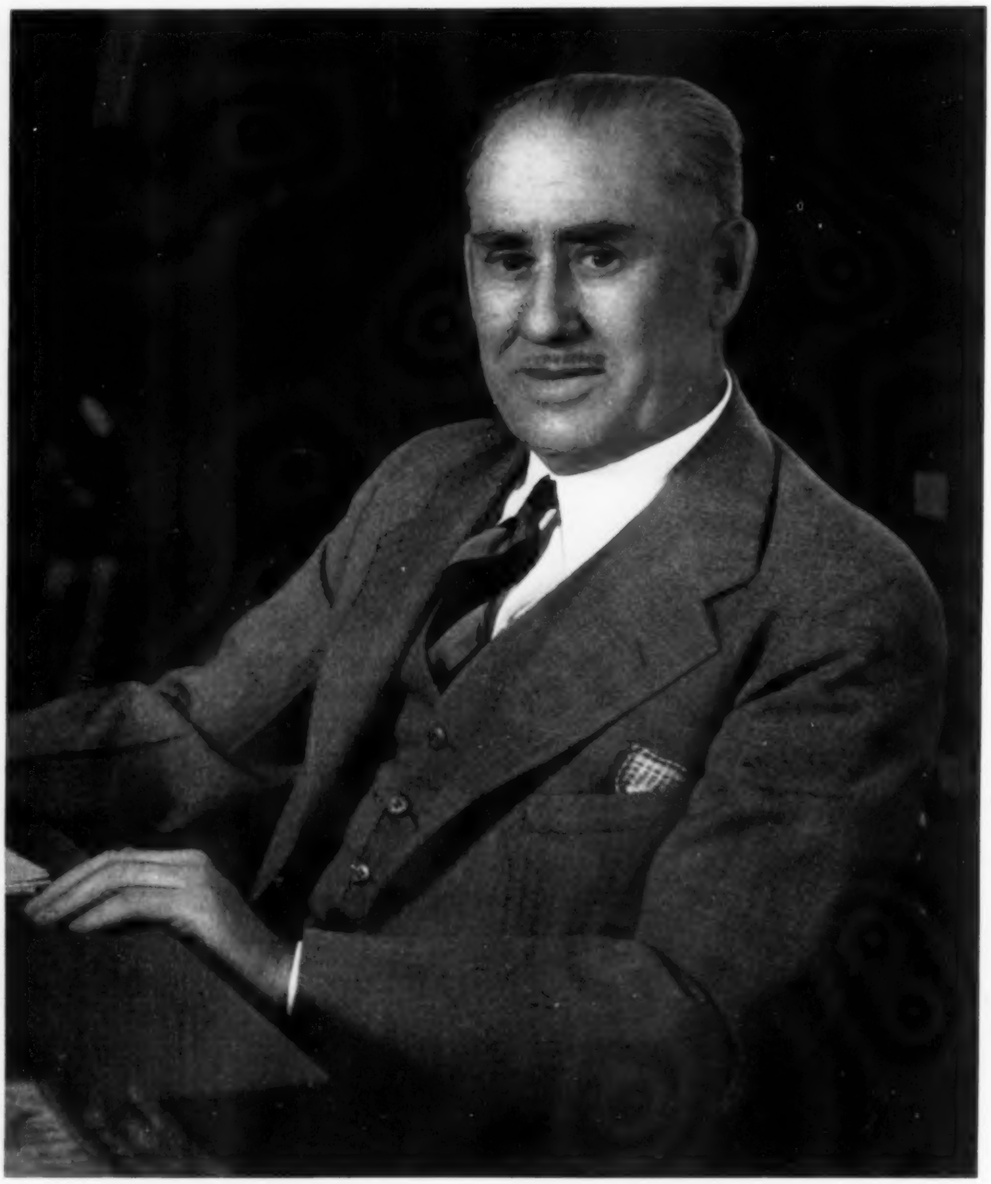
De-hydrogenizers to Protect Alloy Steel from Flakes

Reminded on visiting the Cleveland plant of Steel and Tubes — whose housekeeping arrangements would delight Henry Ford — that its process of electrically welding pipe was described in the very first article of the very first issue of Metal Progress. The story was written by The Editor after a visit to the Youngstown plant of Republic Steel Corp. where pipe up to 16 in. was being made to compete with lap-welded and seamless. Steel and Tubes (now a division of Republic Steel Corp.) has meantime greatly expanded its capacity for mechanical tubing less than 4 in. diameter, mostly made from soft carbon steel, although one department occupies itself with boiler tubing and another with stainless steel . . . . . Accurately cold-rolled strip in coils is fed endwise into a train of forming rolls which bend the edges up to butt, and the seam advances under a pair of wheel electrodes, thus receiving alternating current close to the edges. Heating and side squeezing between lateral rolls is simultaneous; the weld forms with a small flash outside which is cut off as the advancing pipe moves under an appropriate tool. Inside the upset is much smaller; for some uses it stays; in others it is ironed out while still plastic by an interior mandrel; in others it is trimmed off by an interior cutter. Appropriate cooling jets, sizing rolls, and flying shear deliver pipe in 20-ft. lengths, one every 20 sec. Joe Adelson, plant metallurgist, pointed out that the endless continuity of the chip cut from the outer flash is good evidence of a sound weld, but several presses alongside the battery of welders seemed always busy expanding and flattening short samples so the workmen can be sure. *No* fractures are permitted at the seam. . . . . . Boiler tube is normalized in controlled atmosphere, blued, and given the hydrostatic test. Compressed air is rather more searching; for refrigerator tubing a continuous test somewhat like the Sperry rail fissure detector has been devised. This equipment, as exhibited by Sperry Products, passes the tube through coils where it is highly magnetized and then induced currents sent whirling around it normal to the seam, so that any irregularity in the weld will change the expected current enough to operate a warning signal . . . . . Most interesting was the straightening of automobile propeller tubes. These are 100% inspected for length, interior diameter at both ends, and for straightness by rolling under seven Ames gages. In order to avoid "whip" when operating at high speeds these gages must show the tube straight to within 0.010 in. . . . . Shock absorber tubes, made by the million, are about 6 in. long of 1¼-in. o.d. pipe, cold drawn smooth inside — almost polished — and round to ±0.001 in.

Tube Welded Endlessly from Strip

The Society's New President

Oscar E. Harder



A Biographical Note by H. Kenneth Briggs, Miller and Co., Chicago

THE life story of Oscar Edward Harder, familiarly known as "Doc", begins in the colonizing period of the southwestern United States. Lincoln fashion, he was born in a log cabin in Franklin County in Arkansas. After he had partly grown up and spent four years in the rural schools of Arkansas, his family moved overland in a prairie schooner to western Texas and from there to Oklahoma Territory where they took life, according to the times, in a structure half-dugout and half-house with clay floor and sod-built chimney. Here followed years of farm work with intervals of attendance at the rural schools. Then came a few months studying commercial law and bookkeeping, work in a general merchandise store and four years of rural school teaching broken by terms of study at the Normal School.

Though he had never been formally graduated from either grade school or high school, the University of Oklahoma in 1905 admitted him as a special student. In 1910 he received his bachelor's degree, majoring in chemistry, and in 1911 he earned his master's degree and got his first technical job as food chemist with the Kansas State Board of Health. The urge for further study took him to the University of Illinois where he received his doctor's degree in applied chemistry in 1915, with minors in organic chemistry and geology.

At Lewis Institute, Chicago, he worked on cements and concretes for a research committee of the American Society for Testing Materials and the Portland Cement Association. Here he met Ruth Norton, a domestic science teacher, whose cooking ability supplemented her other attractions, and she became Mrs. Harder in 1921.

In the year 1918-19 he held the Alloy Scholarship at Mellon Institute, Pittsburgh, studying uranium. In September of 1919 he was called to the University of Minnesota to succeed Samuel L. Hoyt as professor of metallography.

In the eleven years at Minnesota, and with the help of Ralph L. Dowdell who was to succeed him, Doctor Harder brought that already efficient department to a top rank among our metallurgical schools. His courses in dental metallography were unique. Although students majoring in metallography were few in number, many have made high marks in industry and teaching. Himself indefatigable, he was intolerant of idleness but was adept at helping his students to help themselves. A wide consulting practice included gold alloys, drill rod, bearing metals, rails and steel castings.

In 1930, Harder came to Battelle Memorial Institute in Columbus, Ohio, as assistant director. As is well known, this is an adequately endowed institution for metallurgical and fuel research and development. Here he can give full exercise to his specialty, physical metallurgy. The personal qualities that make him the successful research metallurgist are apparent in his work at Battelle. His ability to recognize essentials, his capacity for thoroughness, and his generous recognition of the achievements of subordinates, bring forth the best efforts of his staff. His dry wit and keen sense of humor temper the stiff pace that he sets by his own hard labor.

A charter member of North West Chapter of , he is a past chairman of both the North West and the Columbus Chapters. 1930 to 1932 he was trustee of the national Society, vice-president of in 1940, and is now president. He has also served on many national committees.

His contributions to the technical press are of unusual scope, ranging from flavoring extracts, through general and organic chemistry, sands and cements, to metallography and metallurgy. He has written or is co-author of two books and some 44 papers; he also holds six patents on steels and alloys. He has lectured before nearly every chapter of the ; his honors include membership in Sigma Xi; he received the Howe Medal from the in 1928 and was Priestley Lecturer at Pennsylvania State College in 1940. He belongs to a long list of technical societies.

But all has not been hard work. He enjoys his home — an evening with the Harder family is a pleasurable privilege. He also loves the outdoors. Handball and golf are his games, to say nothing of a mean hand of bridge. Fishing, his hobby, once claimed a solid week's effort to get a muskellunge. Result — one bite and no fish. Vacations are often in Florida in January where, last winter, he caught a shark which was duly identified as an elasmobranch fish and photographed with the fisherman.

Oscar Harder is a firm believer that, with hard work, thrift, and thoroughness in the daily tasks, youth today has a greater chance in life than he had. is proud of her new president!

Metallographic Preparation *of* Copper-Lead Bearings

By H. L. GRANGE
Research Laboratories Division
General Motors Corp.
Detroit

RECENT WORK IN THE DEVELOPMENT of non-corrosive lubricants has created a need for a more detailed study of the relationship between microstructure and performance of copper-lead bearings. Inclusions, compounds, lead distribution and lead structure are factors in a bearing which have heretofore been obscure because of the difficulty of preparing a microsection in which the copper and lead could be studied in a clear, undistorted image.

Bearings of the 70% copper, 30% lead type present one of the most difficult of these metallographic problems. The almost complete mutual insolubility of copper and lead produces a structure of copper dendrites among which the relatively soft lead solidifies. During the first polishing operations, both metals smear and distort considerably, and subsequent polishing to remove this distorted layer removes an excessive amount of lead. Of course this must be avoided since the microscope requires a common plane of copper and lead for accurate study of size, distribution and structural detail of constituents. Even though the utmost care is taken during polishing, it is almost impossible to avoid a difference in copper and lead levels too great for a common focus. The situation is diagrammed and typical micrographs shown in the group of illustrations on the next page.

After a good deal of experimentation, a method has been developed that offers considerable improvement over the conventional methods of preparing these alloys. This method employs a reagent to remove copper by chemical attack and thereby compensate for the rapid removal of lead during polishing. By alternately etching to remove the copper and then polishing, distorted metal can be cut away and a microsection can be obtained with copper and lead in the same plane.

This copper removing reagent is made of 2½ g. chromic anhydride (of electroplating purity), 50 ml. water and 10 drops concentrated hydrochloric acid. It is a diluted form of chrome regia. Solutions may be made and stored with no loss in effectiveness.

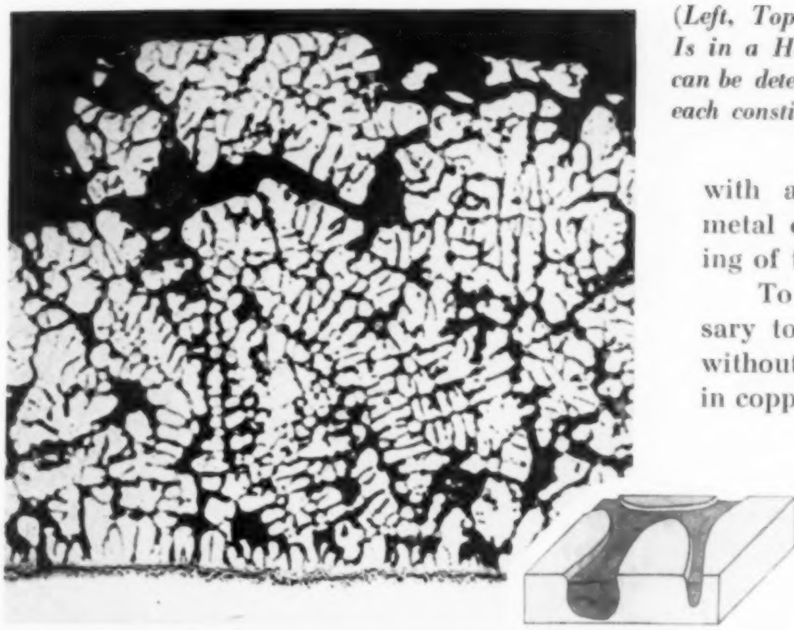
The reagent is applied with a cotton swab with a firm wiping action. Attack can be recognized by an orange discoloration of the copper-lead surface. Occasionally the reagent does not wet the specimen and no reaction occurs; this may be remedied by rubbing the specimen across the final polishing wheel, an action which appears to recondition the surface. It may be necessary to add more hydrochloric acid to the reagent in order to secure the desired action, but acid should be kept at a minimum to prevent "coring". Some structures have a greater tendency to "core" than others, and for these a greater number of alternate etchings and polishings with a minimum attack in each application is recommended.

Alcohol inhibits the reaction and must be kept away from the specimen and out of the reagent.

Other copper removing reagents may be employed, such as a solution of potassium sulphide in water, or a solution of one part 30% hydrogen peroxide and one part ammonium hydroxide. However, the dilute chrome regia described above has been found to be best.

Polishing Procedure — The primary steps in the polishing of copper-lead bearings may be carried out according to conventional metallographic practice. No special equipment is required.

Bearings are usually sectioned with a hand hack saw, filed to eliminate torn and dragged metal, and mounted in hard bakelite. The specimen is then ground on a belt grinder with 50X, 80X, 1/0, 2/0 and 3/0 abrasive belts oiled with kerosene to reduce metal drag and distortion. After these operations, examination



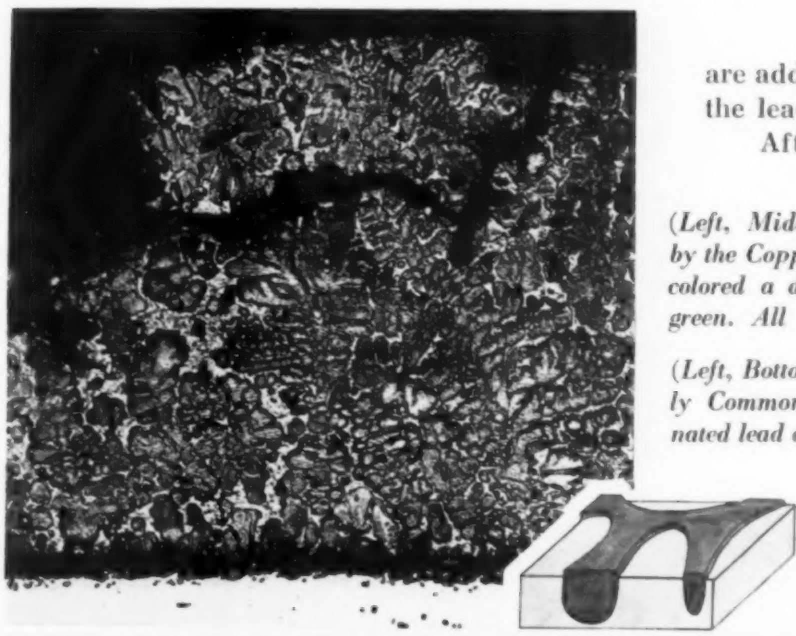
(Left, Top) After Normal Polishing Operation, Copper Is in a Higher Plane Than the Lead. This relationship can be determined by noting the relative focal point of each constituent, and is further illustrated by the sketch

with a microscope will reveal considerable metal distortion and also removal and smearing of the lead.

To complete the preparation, it is necessary to remove scratches and distorted metal without producing any appreciable difference in copper and lead levels.

The specimen is first etched with the copper removing agent and then polished on a horizontal wheel covered with billiard cloth whose fibers have been thoroughly impregnated with levigated lens-polishing rouge. As polishing proceeds, increasing quantities of liquid soap are added to the wheel to minimize distortion of the lead.

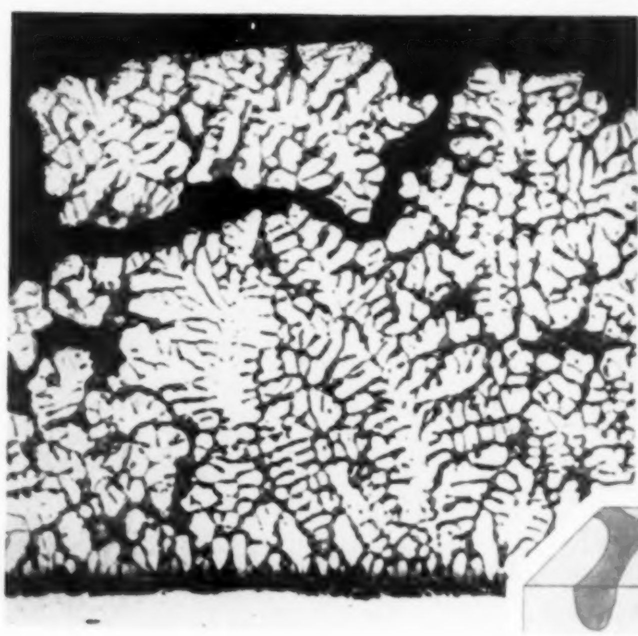
After thus removing the effects of the cop-

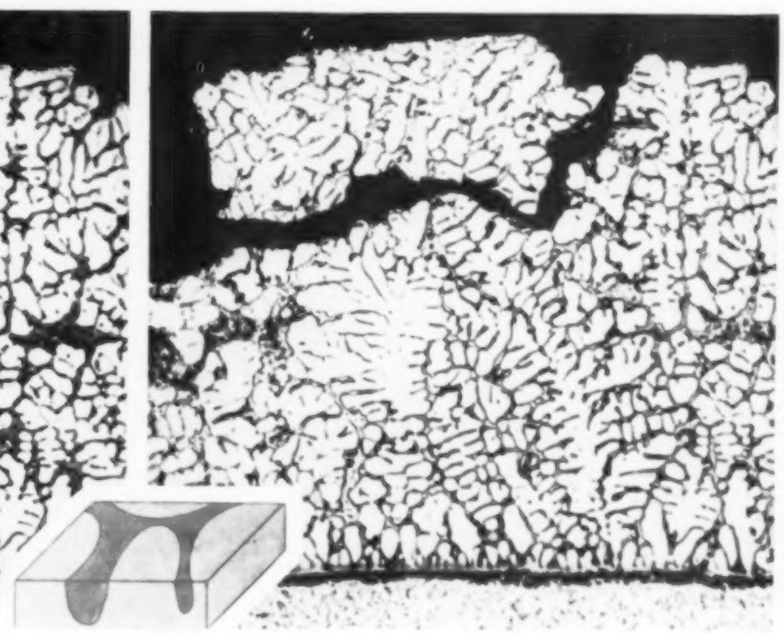


(Left, Middle) Copper-Lead Bearing After Attack by the Copper Removing Agent. The copper will be colored a deep orange and the lead will be colored green. All views in this set are at 100 diameters

(Left, Bottom) Copper and Lead in an Approximately Common Plane. Smeared and abrasive impregnated lead can be clearly seen at higher magnification

(Right, Bottom) Surface Treated With Vilella Lead Reagent to Remove Flowed Lead and Improve Definition. Structure in the lead is clearly shown in views on the next page at higher magnification





per reagent, the surface is examined under a microscope. It will be noted that the number of scratches and amount of distorted metal have been decreased somewhat by this single alternate etch and polish, but several further etching and polishing operations may be required. When no improvement in structure can be noted after successive etching and polishing operations, it may be concluded that the distorted metal has been removed.

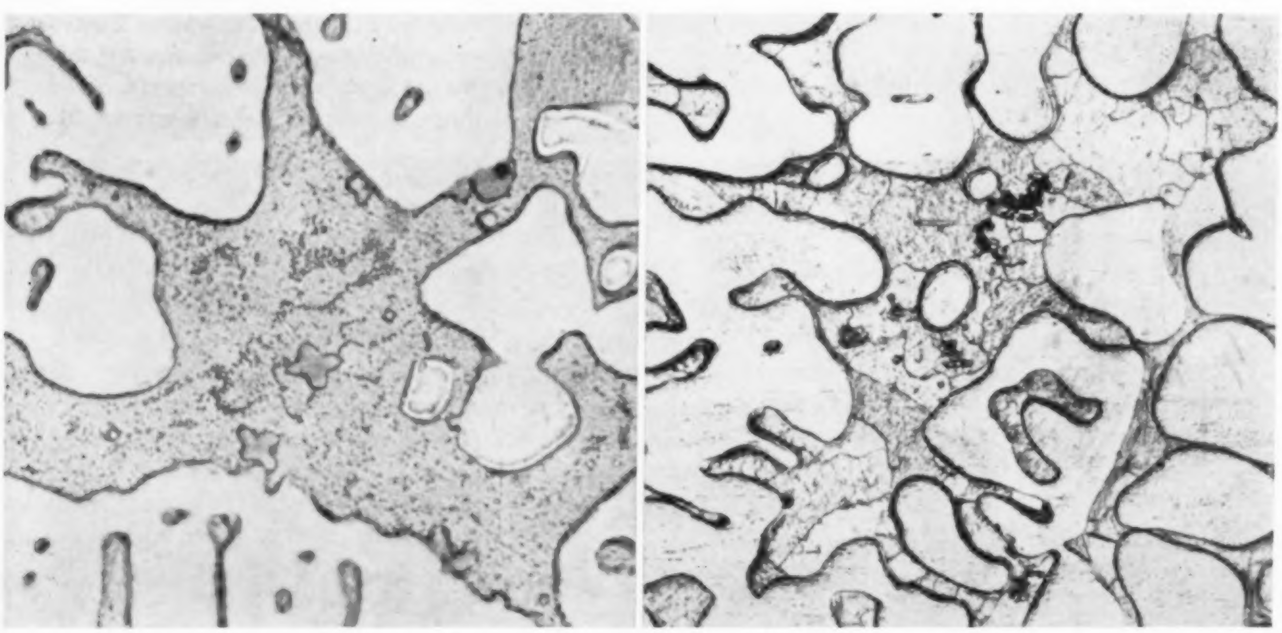
After scratches and distorted metal have been removed, it is next necessary to eliminate any difference in copper and lead levels which may still be present. However, it is best to prevent excessive attack of the reagent in any one application so that no great difference in copper and lead levels can develop in the first place. Although it requires more operations, several repetitions of light etching and light polishing will do this, and in the end will be more expeditious than heavy etching and prolonged polishing. Microscopic examination will reveal which constituent is in the higher plane and which must be removed either by further etching or polishing. By increasing the etching time over the polishing time, copper can be removed more rapidly than lead; by emphasizing the polishing over the etching, lead can be removed more rapidly than copper. Frequent microscopic examination to reveal the relationship of the two metals is essential in order to control the next step — polish or etch. No deleterious effects result from numerous repetitions, although it is desirable to strike the common plane as soon as possible to minimize the difference in level between the bearing metal and the steel backing material.

After the common plane of copper and lead has been attained and the specimen is free of scratches, stain, and coring, VILELLA's lead reagent may be applied to remove any remaining distorted lead and improve the definition of the lead areas. This reagent consists of one part nitric acid, one part glacial acetic acid, and four parts glycerin. It is swabbed lightly on the specimen for a very short time. A somewhat longer time of attack will reveal structure, grain boundaries and general detail within the soft lead.

The steps in this method of preparing copper-lead bearings are illustrated by the set of micrographs and sketches on page 675, showing a single area in various stages.

The value of polishing and etching to remove distorted surface layers on metals has been long recognized, but the combination of this practice with the special reagents for attacking copper is responsible for its great value in preparing copper-lead alloys.

Micrographs at high magnifications representative of the results that can be secured are shown just below.



Detail Within the Lead of a Copper-Lead Bearing, Polished by Methods as Indicated and Etched With Vilella's Reagent. Star-shaped inclusions in left-hand micrograph at 750X are of a blue-purple color. The specimen of the right-hand micrograph at 500X was etched more heavily to develop grain boundaries

The Precipitation Reaction *in* Solid Metal Systems

By MARTIN SEYT

IN THE 1937 ISSUE OF THE *JOURNAL* OF the British Institute of Metals, Dr. MARIE L. V. GAYLER presented a theory of the mechanism of precipitation from metallic solid solution based upon published results of changes in microstructure, mechanical properties, X-ray spectra, electrical resistivity, and density during the aging of alloys of the duralumin type and of some copper-beryllium and copper-silver alloys.

This theory stated that the process of precipitation occurs in two stages. The first stage consists of a "diffusion of solute atoms to planes about which precipitation proper will ultimately take place". Dr. GAYLER assumed that this diffusion will cause an increase in the concentration of solute atoms about the planes of precipitation of the lattice of the solid solution, and will cause an increase in the resistance to deformation and an increase in electrical resistance, but will involve no change in lattice parameter of the solid solution. In the second stage, which directly follows and may overlap the first, "some of the diffusing atoms will form molecules with neighboring atoms of the solvent metal (or other diffusing solute atoms, depending on the constitution of the alloy in question), and these will gradually form groups of molecules". It was further assumed that this grouping of molecules will produce a gradual decrease in electrical resistance and a decrease in the rate of hardening. As the molecular groups increase in size, local stresses will be set up in the solid solution lattice causing diffuseness of the lines of the X-ray spectra. "When a group of molecules thus formed grows to such an extent that the solid solution can no longer withstand the stresses set up, release of these stresses is caused by the rejection of this group from the solid solution lattice and precipitation proper has taken place."

Last year in the same publication, Dr. GAYLER and R. PARKHOUSE presented the results of a research carried out on a pure aluminum-copper alloy in order to check the previous results in an alloy free from the influence of any impurity— a factor wisely considered in the discussion of the earlier paper. They sought thereby to dispel any doubts as to the validity of the experimental curves or of the theory relating to the precipitation phenomenon presented previously.

This new investigation consists of two parts. Part I contains Brinell hardness measurements on an aluminum-copper alloy containing 4% copper aged for prolonged periods at temperatures ranging from 0° C. to the quenching temperature, with a discussion of the relationships between hardness, time, and temperature as these relationships reveal the facts concerning age hardening. Part II correlates the microstructural changes with the changes in hardness during aging.

It is interesting and encouraging to find that the results indicate that the high purity binary alloy exhibits hardening curves similar to those shown by the alloy of more complicated composition, and thus confirm the earlier results in this respect. I am not so sure, however, that the experimental evidence divulged upholds the proposed mechanism; therefore the authors' statement that "the results completely substantiate the theory put forward" is hardly warranted. For instance, I am informed from work in allied fields that a grouping of atoms of the sort postulated by Dr. GAYLER and Mr. PARKHOUSE will cause a *decrease* in electrical resistance, rather than an increase. A critical reader (and I have been accused of being critical) will be distressed by the unreserved manner with which changes in mechanical properties (particularly the occurrence of multiple hardening peaks) are correlated with microstructural changes and changes in electrical resistance and X-ray spectra during aging, and interpreted as support of the proposed theory.

The suggested mechanism of the precipitation reaction itself embraces many singular ideas. Although solute atoms are assumed to diffuse *against* a concentration gradient within the solid solution lattice and to aggregate on certain crystallographic planes, no mention is made of the

nature of the forces or of the mechanism by which this can occur, or why a certain set of crystallographic planes is selected by the diffusing atoms to the exclusion of others. Also I have seen little published evidence justifying the assumption that $CuAl_2$ molecules can exist as such in solid solution or that they can agglomerate into groups. Furthermore, no information is given as to the mechanism by which rearrangement of solute atoms increases resistance to deformation. Without answers to these questions the proposed theory appears somewhat transcendental.

Sadly it must be recorded that these papers are typical of much of the published work on this problem in the following respect: Originally the precipitation reaction was pictured as a spontaneous decomposition of a supersaturated solid solution into a mixture by the separation of a second phase — that is to say, as a simple heterogeneous reaction — a picture appealing because of its simplicity. But because the direction of the observed changes in electrical resistance and density (especially during aging at low temperatures and in the early stages at higher temperatures) is often opposite to that predicted by superficial application of this theory, and because early workers failed to observe changes in microstructure and X-ray spectra, it has been rejected by many investigators in favor of a mechanism involving a nebulous "pre-precipitation association" of the solute atoms within the solid solution lattice. This latter mechanism was to explain these "anomalous" property changes. In this light the precipitation process must be considered as a homogeneous reaction, at least in the early stages. The theories proposed by different investigators, however, are not consistent with one another — each possesses its own peculiarities to explain one or more of the observed variations, but none accounts for all.

Although the properties of solid solutions and of heterogeneous mixtures of particles large enough to be microscopic are quite accurately known, the properties of colloidal systems encountered when one is transformed into the other have not been adequately studied, and thus the interpretation of the variations in properties during the early stages of aging is in many cases unsound. It is vain to try to deduce the mechanism of the reaction without first accurately evaluating the methods of study and considering all possible sources from which property changes may arise. In my opinion much of the controversy over the theory of the mechanism of the precipitation process would never have occurred except by neglect of this highly important point.

Property changes may arise not only as a result of the appearance of a new phase, but also as a result of the depletion of the solid solution in solute atoms. The size of the precipitate particles as well as their total volume must be considered. Effects may arise also from a change in the lattice of the precipitate with time. The special circumstances which attend solid transformations require consideration, such as the strain arising from volume change and from lattice disregistry between precipitate and the solid solution matrix. Nor is it to be assumed that the distribution of the precipitate is random or that the solid solution is uniformly and continuously depleted in solute concentration; additional effects may arise from the fact that they are not.

Furthermore, since each property is directly determined by a different fundamental quantity than any of the others, the effect from each of the above-named sources of change varies for different properties.

Some properties depend mainly upon the number and size of the precipitated particles, whereas others depend more upon the changes in the solid solution matrix. Still others depend mainly upon the strain accompanying precipitation and only indirectly upon precipitation itself. It should be obvious that the integrated change for any given property depends upon the magnitude of the effect of each of the causation factors and the point in time when the effect is exerted. In many cases the overall change of a property may be too complex for good interpretation, and correlation of one property change with another is always hazardous.

Lately more attention has been given by my American friends to the study of methods than formerly, but it seems that these English authors must be behind this trend. The "anomalous" property changes upon which GAYLER's homogeneous reaction mechanism has been founded may be more convincingly explained on the assumption of a pure heterogeneous mechanism with due consideration of all the factors cited above (as illustrated by the work of BECKER, PHILLIPS and BRICK, FINK and SMITH, and MEHL and JETTER). The latter mechanism involves the formation of nuclei of a new phase (not necessarily the equilibrium one, but one of such composition and size as to be stable with respect to its surroundings) by chance encounters of atoms moving from point to point by place interchange — the fluctuation phenomenon — and the growth of these nuclei under a decrease in free energy. The formation of intermediate phases (lattices) is a direct result of the orientation relationships between the two lattices and the Widmanstätten mechanism of lattice transformation. In addition, the assumption of a heterogeneous reaction is founded on much sounder physico-chemical principles and has been applied with success to other types of reactions in which two phases are involved and one spontaneously transforms into the other.

Covered Electrodes for Arc Welding

By LOUIS J. LARSON
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EXTENSIVE ADOPTION OF ARC WELDING as a manufacturing process is due to its inherent advantage over other methods of fabrication. By the use of welding it is possible not only to build many structures cheaper or better, but also to make joints and build equipment that are impracticable by other methods.

Without the development of covered electrodes, and the resulting improvement in the quality of weld metal, this widespread use of welding could not have occurred. Until covered electrodes became available, arc welding was limited to repairs and to the welding of light gage materials or unimportant parts. Now welding is used for joining either heavy or light parts in steel structures subjected to all kinds of service conditions, including the most severe.

Early attempts to develop electrode coverings were prompted by the desire to find a means of stabilizing the arc, and to make the welding process easier for the operator. While arc stability is still a requirement, a coating must accomplish much more to be considered satisfactory. The beneficial effects claimed for various coating compositions are numerous. (For a summary of literature see "Coatings and Fluxes in the Welding of Steel", Welding Research Supplement, *Journal* of the American Welding Society, vol. 18, 1939, p. 154.)

Among the more important functions ascribed to modern coatings for weld rods of steel are the following:

1. To protect the weld metal against contamination.
2. To prevent the loss of alloys contained in the metallic core.
3. To permit the addition of alloys to the weld by additions to the coating.
4. To increase the speed and thus decrease the cost of welding.
5. To reduce spatter.
6. To furnish a slag having certain desired characteristics.
7. To stabilize the arc.
8. To permit the use of alternating current for welding.

Some of the functions enumerated are essential to the success of the welding process; others, though not essential, are desirable from a cost standpoint. This will be more evident from a consideration of each of the functions given above.

Protecting Weld Metal — This is an essential function of any electrode coating. When welds are made in air with bare electrodes (that is, without protection) the molten steel absorbs 0.10 to 0.20% nitrogen and 0.20 to 0.30% oxygen, the latter mostly in the form of FeO, and much of the carbon and manganese in the fused metal is burned out. The resulting deposited metal is hot-short due to the high FeO, and shows aging effects due to nitrogen. Welds made with coated electrodes which protect the weld metal have mechanical properties equivalent to those of low carbon steel. Many published data show the mechanical properties of welds made with bare and coated electrodes; representative values are given in the table on the next page. It is obvious from these figures that the properties of weld metal made without protection against contamination are inadequate for most purposes, and the success of the arc welding process for important engineering purposes depends upon the use of coatings which furnish adequate protection for the molten steel at the joint.

Preventing Loss of Alloys in Core Wire — Coated electrodes are essential when alloy welds are desired, since alloys added to bare electrodes are practically all lost in the arc and the resulting deposit is similar to that obtained with a bare carbon steel wire. Coatings which protect the metal of carbon steel electrodes by excluding the air also prevent the oxidation of the alloying elements of the core wire.

Addition of Alloys to Coating — To successfully produce alloy welds by adding alloys to the coating, it is necessary to prevent the oxidation or contamination of these alloys during their passage through the arc. Fundamentally the problem is the same as the one just above.

Increased Speed — Although the increased speed and consequent reduction in cost of welding brought about by the use of covered electrodes are of great economic importance, these results are only indirectly due to the coating. The smaller sizes of bare electrodes commonly used, operated under proper conditions, melt and deposit metal just as fast as the corresponding sizes of covered electrodes. On heavy material large covered electrodes can be used with high welding currents, whereas bare electrodes are limited to $\frac{3}{16}$ in. diameter regardless of type of work. Thus by removing the size limitations imposed on bare wire welding, covered electrodes may in some cases increase welding speed as much as five times.

Reducing Spatter — Spatter is objectionable for two reasons: (1) It detracts from the appearance of the finished product unless it is removed, and its removal is an added expense and (2) the metal which goes into spatter is wasted and the deposit efficiency (that is, the ratio of weight of metal deposited to weight of electrode consumed) is thus reduced. Bare electrodes do not spatter to an objectionable degree when used under optimum conditions, but under other conditions as much as 50% of the metal may be lost in this way. The amount of spatter with covered electrodes depends to a large extent on the type of coating. With some coatings the spatter loss is only a few per cent over a wide range of operating conditions; with others the spatter may vary from 15 to 50%, depending on conditions.

As previously stated, high spatter results in low efficiency of deposit, but low spatter of covered electrodes does not necessarily indicate high deposit efficiency. When the low spatter is obtained by the use of a heavy coating, the "deposit efficiency" is low because most of the coating goes into the slag and does not contribute to the weight of metal deposited.

Furnishing the Proper Slag — Before considering the desired characteristics of slags, the question may well be asked, "Why have *any* slag?" Slag is said to protect or purify the weld metal and to facilitate certain operations such as overhead welding. However, welds having excellent properties can be made without slag in hydrogen or other protective gases. Also, welds may be made in the vertical and overhead positions with bare wire. Hence slag is not required for these purposes. However, since all commercial electrodes produce slags, it is very important that their characteristics be controlled. The slag must separate readily from the weld metal and must not add harmful constituents to the deposit. It must not interfere with the welding operation, and should be easily removed from the completed joint. For overhead welding, a thin layer of slag covering the entire bead is desirable. For fillet welding, a heavy layer covering the bead results in a smoother weld. These, and many other characteristics of slags, are effected by the composition of the coating.

Stabilizing the Arc is a great help to the operator in striking and maintaining an arc. It requires considerable skill and a high degree of attention to maintain an arc with bare wire but it is comparatively easy to do so with covered electrodes. Greater arc stability not only relieves the strain on the welding operator, but also results in a much more consistent weld

Comparison of Welds Made With Bare and With Coated Electrodes

	Yield Point Psi.	Ultimate Strength Psi.	Elongation in 2 In., %	Reduction of Area, %	Bend Elongation %	Charpy Impact, Ft-lb.
0.20 to 0.30% carbon steel plate (as-rolled)	30,000 to 40,000	55,000 to 65,000	35 to 50	50 to 70		20 to 30
Welds made with bare electrodes						
¼-in. plate (as welded)	40,000 to 45,000	50,000 to 60,000	6 to 15		15 to 30	
1-in. plate (stress relieved)	20,000 to 45,000	25,000 to 55,000	1 to 7	0 to 7	1 to 12	1 to 2
Welds made with coated electrodes						
¼-in. plate (as welded)	40,000 to 55,000	55,000 to 70,000	20 to 35		30 (min.)	
1-in. plate (stress relieved)	40,000 to 55,000	55,000 to 70,000	25 to 45	40 to 70	30 (min.)	25 to 45
Over 1-in. plate (stress relieved)	40,000 to 55,000	55,000 to 70,000	25 to 45	40 to 70	30 (min.)	25 to 45

Photo by B. H. Chatto
in Westinghouse's Arc Welding Shop

quality due to fewer interruptions of the arc.

Use of Alternating Current — In locations such as corners of structures where "arc blow" is troublesome with direct current, the use of alternating current is very helpful. Without coated electrodes, it is practically impossible to hold an arc on alternating current, since the arc tends to extinguish each time the current passes through the zero value. Coated electrodes overcome this difficulty, but not all coated electrodes are suitable for use on alternating current. However, there are available many electrodes which are, and they satisfy a definite need.

Summarizing; the most important and perhaps the only indispensable function of a weld rod coating is to furnish a protective atmosphere for the metal. This makes it possible not only to produce weld metal of high quality in carbon steel, but also to produce alloy welds by alloying either the core wire or the coating. Indirectly, the protective atmosphere is also responsible for the greater speed of welding possible with covered electrodes of large diameters. Some of the other benefits, such as reducing spatter, stabilizing the arc, and permitting the use of alternating current, are desirable and important economically, but not essential to the use of arc welding as a manufacturing process. Even though coated electrodes were no better than bare wire in these latter respects, arc welding would be used extensively.

Constituents of Coatings

The chemical elements and compounds which have been tried are numerous. Among them are:

1. Sodium silicate, which is almost universally used as a binder, sometimes in combination with potassium silicate.
2. Ferro-alloys, or sometimes pure metals, which form beneficial alloys with iron.
3. Oxides of many metals.
4. Many of the carbonates and silicates.
5. Carbohydrates, particularly cellulose in the form of wood-flour, cotton, or starch.
6. Carbonaceous materials such as charcoal and coke.
7. Complex mineral compounds, such as asbestos, talc, mica, kaolin, feldspar and ilmenite.

The number of coating mixes that may be made by combining two or more of these ingredients is almost unlimited and the task of determining the best coating for a given purpose is slow and laborious.

The reactions which occur in the arc are complex, and it is difficult to predict the effect of any constituent of a coating. The behavior of one ingredient may be affected by the presence of another, and in some cases minor variations in the analysis of a constituent produce unexpected results.

Very little information on what takes place in the arc has been published, and more fundamental data are required to determine the laws which govern the reactions there. On the action of a cellulosic type of coating, some data are available in an article by the present writer in the *Journal* of the American Welding Society for October 1936 entitled "An Exploration of a Modern Welding Arc". The coating studied consisted of wood-flour, silica-flour, kaolin, ferromanganese and a sodium silicate binder. The cellulose, $C_6H_{10}O_5$, is broken up into CO and H_2 with small amounts of CO_2, H_2O and O_2. Such a gas mixture is "reducing" to the metallic oxides that might form, and when produced in sufficient quantity to exclude the air it not only prevents oxidation of the constituents of the core wire and the coating during their passage through the arc, but it also reduces some of the oxides present in the coating. This is indicated by the fact that approximately 0.20% silicon was added to the weld metal by reduction of some of the SiO_2 in the coating. Obviously, an atmosphere which will reduce SiO_2 will also reduce many metallic oxides.

The gases produced in the arc by the coating affect the voltage and the energy of the arc. This in turn affects the fluidity of the metal, the amount of penetration, and the degree of heat treatment of the weld and adjacent stock.

Although coating compositions are largely empirical, the purpose of adding certain constituents is well recognized. Ferromanganese, which is generally used, is added to control the manganese of the weld deposit. Other ferroalloys are added when it is desired to produce alloy welds. Titanium compounds are used in most coatings designed for welding in vertical or overhead positions.

Classification of Coatings

Based on composition, it is difficult to classify commercial coatings. A division into the following three classes has been suggested:

(1) Organic, (2) inorganic and (3) mixed, organic with inorganic. However, no clear-cut classification can be made on this basis. So-called organic coatings seldom contain more than 25% by weight of organic material, and many so-called inorganic coatings contain some organic substances. A division into inorganic and mixed may be possible, but is not very enlightening.

It has also been proposed to designate electrodes as (1) gas-shielded and (2) slag-shielded. Such a classification appears to be neither accurate nor easy to make. All commercial coatings produce slag, but it is difficult to visualize how these slags shield the metal during its passage through the arc. Two hypotheses have been advanced, (1) the slag forms a sleeve around the arc, (2) the slag surrounds each particle of metal. It is evident by observing the arc of any covered electrode that the slag forms no sleeve around the arc but falls off the end of the coating in separate drops. In view of the large number and small size of the metal particles passing through the arc, it is also inconceivable that each one can be coated with slag. Hence, the slag can furnish very little protection for the metal during its passage from electrode to joint through the arc, at which time shielding is very essential.

Air must be excluded to protect the metal in the arc, and it appears that the only effective medium for this purpose is a protective gas or vapor. These gases may be formed by *(a)* the disintegration of such materials as carbohydrates; *(b)* the reaction of carbonaceous materials with oxides, including water; and/or *(c)* the vaporization of some constituents of the coating. The amount of gas or vapor produced by equal weights of various coatings varies greatly, and it is probably for this reason that the thickness of the gas-producing coatings is only about one-half that on the "slag-shielded" electrodes. In the light of available information, it appears that for all types of coatings the protection in the arc space is due to gas or vapors and not to slag, and the term "slag-shielded" is a misnomer.

Although it is difficult to set up a clear-cut classification based on coating composition, it is possible to divide commercial electrodes into groups based upon the uses for which they are best adapted.

Most manufacturers making a complete line of electrodes furnish four principal types for mild steel. The name or number assigned to each type by one manufacturer has no significance in the nomenclature used by another, and as yet there is no generally accepted designation for the several groups by various code or regulatory bodies. For convenience in this discussion, the four groups will be designated as *A*, *B*, *C* and *D* respectively.

Group A. Heavily coated electrodes for downhand welding, particularly for groove welds in medium and heavy plates and to some extent for positioned fillets (where the surface of the weld is approximately horizontal). They are used for welding boilers, pressure vessels, heavy machinery and other structures requiring welds of the highest quality. Deposited metal will meet all code requirements including X-ray inspection. Most of the electrodes of this group are used with direct current on reversed polarity (electrode positive) but many of them also operate satisfactorily on straight polarity and on alternating current.

Group B. Electrodes having coatings of medium thickness for welding in all positions and for all types of welds. Although these electrodes may be used for downhand welding, they are less desirable than those of Group *A* for this purpose except on thin stock. Weld metal deposited with those electrodes meets code requirements, including X-ray inspection, but the ductility is generally less than for Group *A*. Most of the electrodes of this group operate only on reversed polarity, direct current.

Group C. Electrodes having a relatively thin coating for welding in all positions. They are used for welding *(Continued on page 712)*

Temperature Conversions

Albert Sauveur type of table. Look up reading in middle column; if in degrees Centigrade, read Fahrenheit equivalent in right hand column; if in degrees Fahrenheit, read Centigrade equivalent in left hand column. Values as printed in "Bethlehem Alloy Steels".

−459.4 to 0

C		F
−273	−459.4	
−268	−450	
−262	−440	
−257	−430	
−251	−420	
−246	−410	
−240	−400	
−234	−390	
−229	−380	
−223	−370	
−218	−360	
−212	−350	
−207	−340	
−201	−330	
−196	−320	
−190	−310	
−184	−300	
−179	−290	
−173	−280	
−169	−273	−459.4
−168	−270	−454
−162	−260	−436
−157	−250	−418
−151	−240	−400
−146	−230	−382
−140	−220	−364
−134	−210	−346
−129	−200	−328
−123	−190	−310
−118	−180	−292
−112	−170	−274
−107	−160	−256
−101	−150	−238
−96	−140	−220
−90	−130	−202
−84	−120	−184
−79	−110	−166
−73	−100	−148
−68	−90	−130
−62	−80	−112
−57	−70	−94
−51	−60	−76
−46	−50	−58
−40	−40	−40
−34	−30	−22
−29	−20	−4
−23	−10	14
−17.8	0	32

0 to 100

C		F	C		F
−17.8	0	32	10.0	50	122.0
−17.2	1	33.8	10.6	51	123.8
−16.7	2	35.6	11.1	52	125.6
−16.1	3	37.4	11.7	53	127.4
−15.6	4	39.2	12.2	54	129.2
−15.0	5	41.0	12.8	55	131.0
−14.4	6	42.8	13.3	56	132.8
−13.9	7	44.6	13.9	57	134.6
−13.3	8	46.4	14.4	58	136.4
−12.8	9	48.2	15.0	59	138.2
−12.2	10	50.0	15.6	60	140.0
−11.7	11	51.8	16.1	61	141.8
−11.1	12	53.6	16.7	62	143.6
−10.6	13	55.4	17.2	63	145.4
−10.0	14	57.2	17.8	64	147.2
−9.4	15	59.0	18.3	65	149.0
−8.9	16	60.8	18.9	66	150.8
−8.3	17	62.6	19.4	67	152.6
−7.8	18	64.4	20.0	68	154.4
−7.2	19	66.2	20.6	69	156.2
−6.7	20	68.0	21.1	70	158.0
−6.1	21	69.8	21.7	71	159.8
−5.6	22	71.6	22.2	72	161.6
−5.0	23	73.4	22.8	73	163.4
−4.4	24	75.2	23.3	74	165.2
−3.9	25	77.0	23.9	75	167.0
−3.3	26	78.8	24.4	76	168.8
−2.8	27	80.6	25.0	77	170.6
−2.2	28	82.4	25.6	78	172.4
−1.7	29	84.2	26.1	79	174.2
−1.1	30	86.0	26.7	80	176.0
−0.6	31	87.8	27.2	81	177.8
0.0	32	89.6	27.8	82	179.6
0.6	33	91.4	28.3	83	181.4
1.1	34	93.2	28.9	84	183.2
1.7	35	95.0	29.4	85	185.0
2.2	36	96.8	30.0	86	186.8
2.8	37	98.6	30.6	87	188.6
3.3	38	100.4	31.1	88	190.4
3.9	39	102.2	31.7	89	192.2
4.4	40	104.0	32.2	90	194.0
5.0	41	105.8	32.8	91	195.8
5.6	42	107.6	33.3	92	197.6
6.1	43	109.4	33.9	93	199.4
6.7	44	111.2	34.4	94	201.2
7.2	45	113.0	35.0	95	203.0
7.8	46	114.8	35.6	96	204.8
8.3	47	116.6	36.1	97	206.6
8.9	48	118.4	36.7	98	208.4
9.4	49	120.2	37.2	99	210.2
			37.8	100	212.0

100 to 1000

C		F	C		F
38	100	212	260	500	932
43	110	230	266	510	950
49	120	248	271	520	968
54	130	266	277	530	986
60	140	284	282	540	1004
66	150	302	288	550	1022
71	160	320	293	560	1040
77	170	338	299	570	1058
82	180	356	304	580	1076
88	190	374	310	590	1094
93	200	392	316	600	1112
99	210	410	321	610	1130
100	212	413.6	327	620	1148
104	220	428	332	630	1166
110	230	446	338	640	1184
116	240	464	343	650	1202
121	250	482	349	660	1220
127	260	500	354	670	1238
132	270	518	360	680	1256
138	280	536	366	690	1274
143	290	554	371	700	1292
149	300	572	377	710	1310
154	310	590	382	720	1328
160	320	608	388	730	1346
166	330	626	393	740	1364
171	340	644	399	750	1382
177	350	662	404	760	1400
182	360	680	410	770	1418
188	370	698	416	780	1436
193	380	716	421	790	1454
199	390	734	427	800	1472
204	400	752	432	810	1490
210	410	770	438	820	1508
216	420	788	443	830	1526
221	430	806	449	840	1544
227	440	824	454	850	1562
232	450	842	460	860	1580
238	460	860	466	870	1598
243	470	878	471	880	1616
249	480	896	477	890	1634
254	490	914	482	900	1652
			488	910	1670
			493	920	1688
			499	930	1706
			504	940	1724
			510	950	1742
			516	960	1760
			521	970	1778
			527	980	1796
			532	990	1814
			538	1000	1832

1000 to 2000

C		F	C		F
538	1000	1832	816	1500	2732
543	1010	1850	821	1510	2750
549	1020	1868	827	1520	2768
554	1030	1886	832	1530	2786
560	1040	1904	838	1540	2804
566	1050	1922	843	1550	2822
571	1060	1940	849	1560	2840
577	1070	1958	854	1570	2858
582	1080	1976	860	1580	2876
588	1090	1994	866	1590	2894
593	1100	2012	871	1600	2912
599	1110	2030	877	1610	2930
604	1120	2048	882	1620	2948
610	1130	2066	888	1630	2966
616	1140	2084	893	1640	2984
621	1150	2102	899	1650	3002
627	1160	2120	904	1660	3020
632	1170	2138	910	1670	3038
638	1180	2156	916	1680	3056
643	1190	2174	921	1690	3074
649	1200	2192	927	1700	3092
654	1210	2210	932	1710	3110
660	1220	2228	938	1720	3128
666	1230	2246	943	1730	3146
671	1240	2264	949	1740	3164
677	1250	2282	954	1750	3182
682	1260	2300	960	1760	3200
688	1270	2318	966	1770	3218
693	1280	2336	971	1780	3236
699	1290	2354	977	1790	3254
704	1300	2372	982	1800	3272
710	1310	2390	988	1810	3290
716	1320	2408	993	1820	3308
721	1330	2426	999	1830	3326
727	1340	2444	1004	1840	3344
732	1350	2462	1010	1850	3362
738	1360	2480	1016	1860	3380
743	1370	2498	1021	1870	3398
749	1380	2516	1027	1880	3416
754	1390	2534	1032	1890	3434
760	1400	2552	1038	1900	3452
766	1410	2570	1043	1910	3470
771	1420	2588	1049	1920	3488
777	1430	2606	1054	1930	3506
782	1440	2624	1060	1940	3524
788	1450	2642	1066	1950	3542
793	1460	2660	1071	1960	3560
799	1470	2678	1077	1970	3578
804	1480	2696	1082	1980	3596
810	1490	2714	1088	1990	3614
			1093	2000	3632

2000 to 3000

C		F	C		F
1093	2000	3632	1371	2500	4532
1099	2010	3650	1377	2510	4550
1104	2020	3668	1382	2520	4568
1110	2030	3686	1388	2530	4586
1116	2040	3704	1393	2540	4604
1121	2050	3722	1399	2550	4622
1127	2060	3740	1404	2560	4640
1132	2070	3758	1410	2570	4658
1138	2080	3776	1416	2580	4676
1143	2090	3794	1421	2590	4694
1149	2100	3812	1427	2600	4712
1154	2110	3830	1432	2610	4730
1160	2120	3848	1438	2620	4748
1166	2130	3866	1443	2630	4766
1171	2140	3884	1449	2640	4784
1177	2150	3902	1454	2650	4802
1182	2160	3920	1460	2660	4820
1188	2170	3938	1466	2670	4838
1193	2180	3956	1471	2680	4856
1199	2190	3974	1477	2690	4874
1204	2200	3992	1482	2700	4892
1210	2210	4010	1488	2710	4910
1216	2220	4028	1493	2720	4928
1221	2230	4046	1499	2730	4946
1227	2240	4064	1504	2740	4964
1232	2250	4082	1510	2750	4982
1238	2260	4100	1516	2760	5000
1243	2270	4118	1521	2770	5018
1249	2280	4136	1527	2780	5036
1254	2290	4154	1532	2790	5054
1260	2300	4172	1538	2800	5072
1266	2310	4190	1543	2810	5090
1271	2320	4208	1549	2820	5108
1277	2330	4226	1554	2830	5126
1282	2340	4244	1560	2840	5144
1288	2350	4262	1566	2850	5162
1293	2360	4280	1571	2860	5180
1299	2370	4298	1577	2870	5198
1304	2380	4316	1582	2880	5216
1310	2390	4334	1588	2890	5234
1316	2400	4352	1593	2900	5252
1321	2410	4370	1599	2910	5270
1327	2420	4388	1604	2920	5288
1332	2430	4406	1610	2930	5306
1338	2440	4424	1616	2940	5324
1343	2450	4442	1621	2950	5342
1349	2460	4460	1627	2960	5360
1354	2470	4478	1632	2970	5378
1360	2480	4496	1638	2980	5396
1366	2490	4514	1643	2990	5414
			1649	3000	5432

Commercial Aspects *of* Hardenability Tests

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THE SUBJECT OF THE HARDENABILITY of steel has been growing in importance for the past few years and has come to be one of the most discussed topics in ferrous metallurgy. When we analyze the conception of hardenability we discover that it covers probably the most important step in the heat treatment of steel, namely the hardening process. Control of hardenability is one of the main objectives in the control of composition and grain size of steel, and the cost of expensive alloys in steel is commonly justified by the gain of deep hardenability.

In choosing steel for any part which requires heat treatment, the hardenability of the steel becomes a first consideration. The design of the part usually determines whether water quenching or oil quenching is desired, and the design and size of the part determine the rate of cooling at any point in the part. The choice of steels is limited to those which will harden at the rate of cooling needed, and often is the least expensive steel that will harden with the required rate of cooling.

While the ideal method of choosing a proper steel involves the above considerations, unfortunately we do not have much data giving us the cooling rates of various parts.

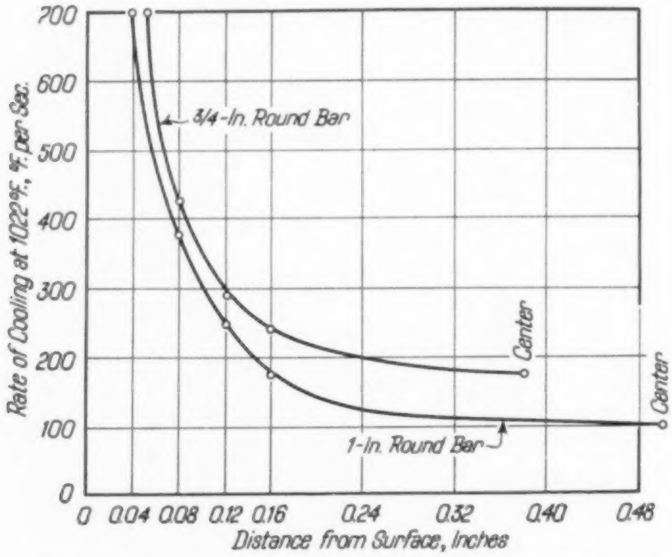
The rate of cooling of some of the common sizes of bars at the surface and center and at various points between surface and center has been determined by investigators in several countries. Notable studies on the subject have been published by ⊕, such as H. J. FRENCH's book entitled "The Quenching of Steels", and HOWARD SCOTT's article in *Transactions* in 1934. Data from such sources may be used (but only to a limited extent) to approximate the cooling rate for commercial parts of nearly the same size and shape as the test bars.

In an effort to utilize the published data the table below and the first chart on the next page were prepared from SCOTT's work giving the rate of cooling of several common bar sizes, and the rate of cooling at various points of a 1-in. round bar and a ¾-in. round bar, water quenched from 1508° F. It will be noted from

Cooling Rates of Round Bars, in ° F. per Sec., as Determined by Scott

Bar Size, In.	Rate of Cooling at 1022° F., Quenched From 1508° F.						Rate of Cooling at 1328° F., Quenched From 1607° F.	
	In Agitated Water				In Agitated Oil		In Still Water	In Still Oil
	At Surface	At 0.04 In. Below Surface	At 0.16 In. Below Surface	At Center	At Surface	At Center	At Center	At Center
½	..	..	..	320	..	115	330	115
¾	..	..	..	180	..	88	185	72
1	1800	790	183	101	135	49	108	47
1½	..	..	..	48	..	29	54	29
2	..	650	115	27	..	18	31	18
3	..	560	104	13	..	9.4	14	9.2
4	..	495	99	..	..	..	8.5 *(a)*	5.5 *(a)*

(a) Determined in General Motors' Research Laboratory.



Cooling Rates of Small Round Bars, at Various Depths Below Surface, When Quenched From 1508° F. Into Agitated Water. The values refer to the rate of change in temperature as the steel cools through 1022° F. (near the temperature where austenite in carbon steels changes to martensite with the maximum speed). Data by Scott

the curves that there is a very fast drop in rate of cooling for the first 1/8 in. from the surface and a relatively slow drop for the last 1/4 in.

Many parts, if not most in automotive application, have shapes which require special study to determine their rate of cooling when quenched. It was therefore thought worth while to determine the rate of cooling on a few gears, and a Chevrolet main drive gear, as shown in the photograph, was measured. Since the stress in this gear is highest at the base of the tooth, this place was chosen for study, and a measurement of cooling conditions made at a point 0.050 in. below the surface.

To do this two holes 0.052 in. in diameter were drilled 1/32 in. apart and 0.050 in. deep. A thermocouple wire 0.025 in. in diameter was welded at the bottom of each hole and the small space between the wire and steel filled with high temperature cement. The gear was then heated to 1490° F., held at heat for 1 hr. and quenched in oil (viscosity, 90 sec. at 100° F.) whose temperature was 90° F. The cooling rate was determined with Leeds and Northrup "Speedomax" equipment. The results of this test are shown in the table above, which contains the cooling rate at 1300 and at 1000° F., and the time to cool from 1100 to 900° F.

The rate of cooling in oil was determined 0.050 in. below the surface of the gear teeth because it is desirable to have a good hardened structure at least that deep. It is apparent that the steel suitable for this part should have sufficient hardenability to develop a fully hardened structure with the rate of cooling as indicated in this experiment, namely 55° F. per sec. when passing through 1300° F.

Similar tests were made on the angle drive gear for Chevrolet trucks and the countershaft gear and results are also listed in the table. The countershaft gear is somewhat larger in diameter than the main drive gear but the shaft is hollow, enabling the oil to circulate through. For this reason the rate of cooling of this gear is faster than the main drive gear whose shaft is solid.

It is to be expected that the cooling rate at the base of the tooth is slower than at other locations on the tooth because the surface from which heat can be conducted is small compared to the mass in its vicinity, just as the cooling rate would be fast at the top of the tooth at the corners where the reverse is true. In testing gears for hardness it is unfortunately not convenient to test them at the base of the tooth — the place where they are most likely to be soft — and the only location where a test other than file can be used is at the top of the gear where they are most likely to be hard.

Now it is quite obvious (even without these experiments) that the heavy truck gear must be made of a different steel or have a different heat treatment than the lighter drive gear. The problem we face is to make an economical choice of steels which will harden properly in the respective gears. To solve it we must have some hardenability data for the steels to be considered.

An easy means of determining the degree of hardening with various rates of cooling is to

Cooling Rates 0.050 In. Below Surface at Base of Tooth

	Main Drive Gear	Truck Angle Drive Gear	Countershaft Gear
Quenched from °F.	1490	1700	1490
Cooling rate at 1300° F., °F. per sec.	55	17	70
Cooling rate at 1000° F., °F. per sec.	38	8	60
Time to cool from 1100 to 900° F., sec.	5.5	25	3
Weight, lb.	5	25½	3
Kind of steel	S.A.E. 5145	GM-X-4620	S.A.E. 5145

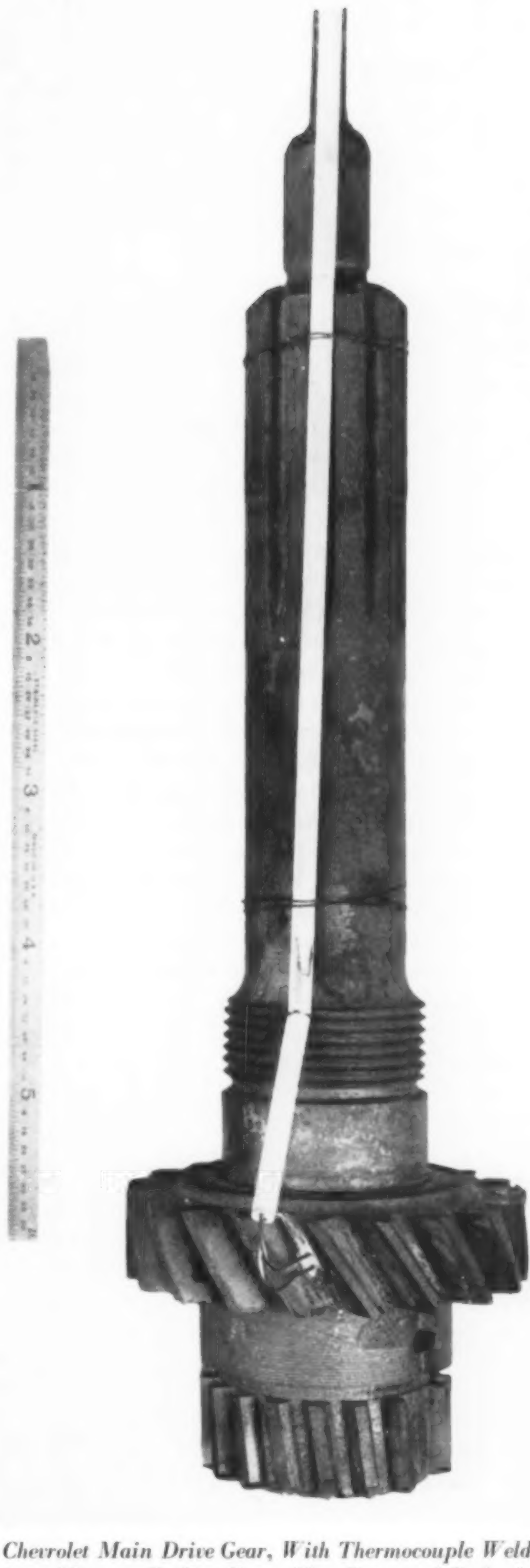
make a hardenability test by the end-quench method. It involves cooling a bar 1 in. in diameter and 3 in. long by spraying water on one face. The hardness is then measured along the bar from the water cooled face to the opposite face. The test piece as shown in the center of the group on page 688 is so small that it can easily be heated in a container with cast iron chips to reduce scaling, and since water cooling is used scaling is not so important. Furthermore, a very uniform cooling rate is obtained at the water cooled face so that reproducibility is good. This test is well suited for alloy steels and for deep hardening steels.

For shallow hardening steels the so-called "L" bar is used with cupped end ("L" indicating low hardenability). It is sketched at the left of the group at the top of page 688. The only difference in the procedure is that the free height of the water column sprayed into this "L" bar is changed to 4 in.

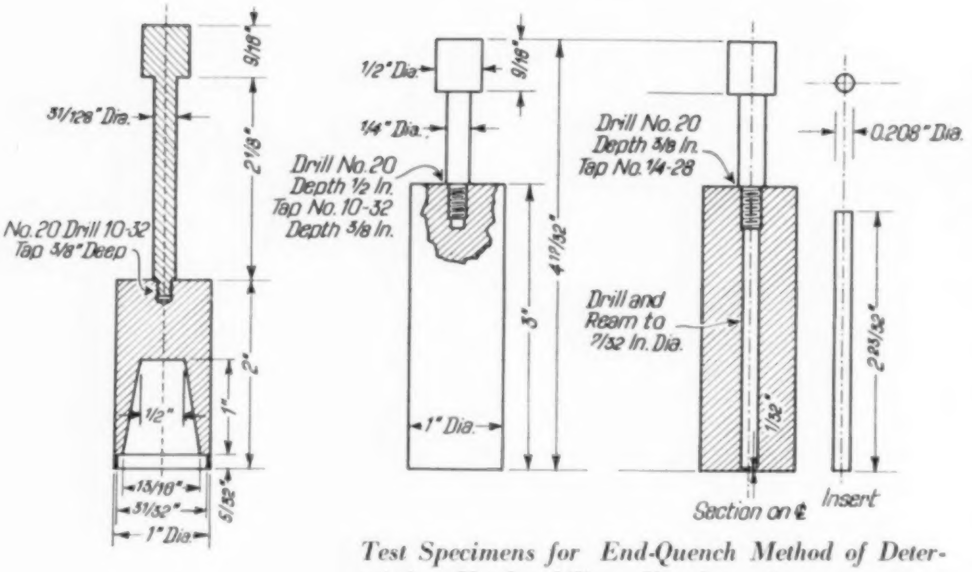
If the steel to be tested is less than 1 in. round but not less than ½ in. round the cylindrical bar can be used except the diameter will be that of the steel bar to be tested. When the size of the steel bar or shape does not permit making a ½-in. round bar from it, the modification shown at the right of the group is used. The test piece is machined to 0.208 in. diameter, 2.72 in. long, and dropped into the central slot in the hardenability bar. Before dropping the test piece into the bar, about 0.2 g. of Woods metal is placed in the hole and the bar heated till the fusible metal liquefies. The test piece is then placed in the bar, a small piece of asbestos paper put on top of it, and the adapter screwed down against the asbestos paper. This gives good metallic contact against the water cooled end. The bar is then heated about 1 hr. to the required temperature and cooled on the standard fixture.

We have tested several steels in the 1-in. round size and in the 0.208-in. size and obtained the same result with each test bar.

In quenching any of these bars (and the 1-in. solid bar is utilized for the following discussion) the cooling rate of the bar varies according to the distance from



Chevrolet Main Drive Gear, With Thermocouple Welded in to Measure Cooling Rates Near Bottom of Carburized Case at Base of Tooth, Judged to Be the Critical Spot



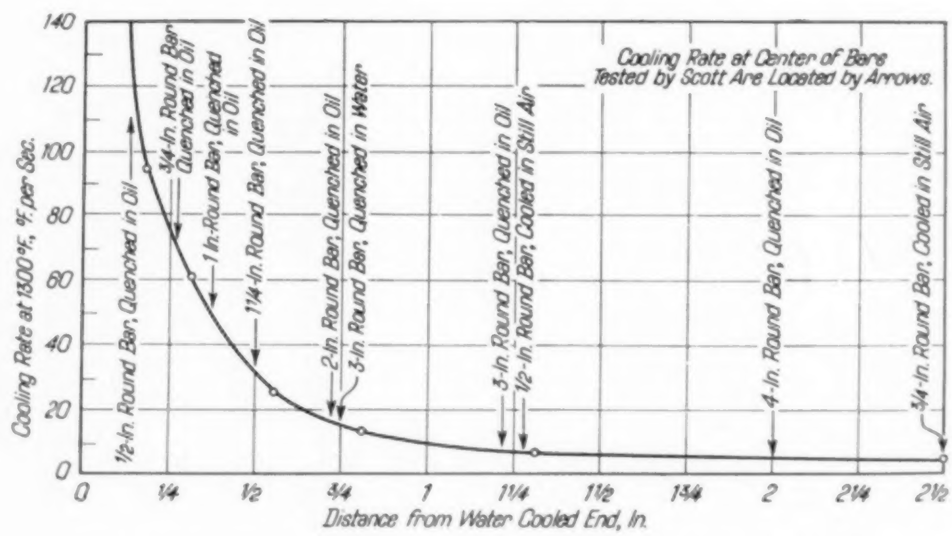
Test Specimens for End-Quench Method of Determining Hardenability. Usual specimen at center; "L" bar for steels of low hardenability at left; drilled bar at right for steels available only in small sizes

the water cooled face, and has been determined at various locations. This experiment was done using S.A.E. 1095 steel and cooling from 1700° F. The curve at the bottom of this page shows the cooling rates obtained at 1300° F.; on this same curve are noted the cooling rates obtained at the center of various round bars tested by Mr. Scott and listed in the table on page 685.

To return now to our problem of selecting desirable steels for automobile gears, we hardened five steels of the 0.45% carbon grade by the end-quench method, determined their surface hardness at various distances from the water cooled end, and the results are plotted in the graph at the bottom of the opposite page. At the top of the chart will be seen figures, drawn from the previous curve, representing the actual cooling rates through 1300° F. at these respective locations. (It should be borne in mind that the cooling rates listed hold for the particular point only and that the plotting of the curve is done according to the distance from the water cooled end.)

The cooling rates noted at the top of the graph, having been determined on S.A.E. 1095 steel by quenching at 1700° F., do not apply exactly to these five steels, and must be regarded as approximations. Having these limitations in mind we may examine this chart to determine which of the steels would be suitable for the main drive gear. If we require a hardness of Rockwell C-57 in the as-quenched condition 0.050 in. below the surface (the actual hardness found in the quenched gear after sectioning) it is evident that S.A.E. 5145, 6145 and 4145 are the steels of this group that would give this hardness when cooled at a rate of 55° F. per sec., the rate at which the part actually will cool, as determined by the direct experiment described at the outset.

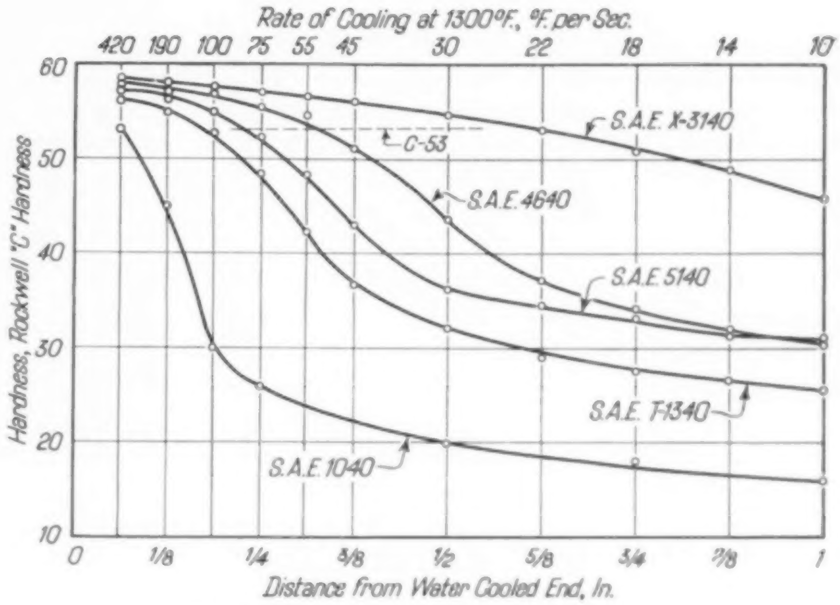
If we were to choose a steel with 0.40% carbon instead of 0.45% it would be necessary to lower our hardness requirement in the as-quenched condition. In this case we might accept a hardness of C-53 in the as-quenched condition. The last chart shows the hardenability of a number of these 0.40% carbon steels. From this chart it is evident that of the group of steels listed only the S.A.E. X-3140 and 4640 can be used to give this a greater hardness at the cooling rate (55° F. per sec.) which will exist at the required region when the part is quenched in production.



End-Quench Bar, 1 In. Diameter, of S.A.E. 1095 Steel Was Cooled From 1700° F. and Cooling Curves at the Surface Determined at Various Distances From the End. Rates of cooling at 1300° F. in ° F. per sec. were computed from these cooling curves and plotted in the above graph

The countershaft gear cools at a little higher rate (70° F. per sec., as shown in the second table), and it appears that all the alloy steels containing 0.45% carbon would harden properly in this part.

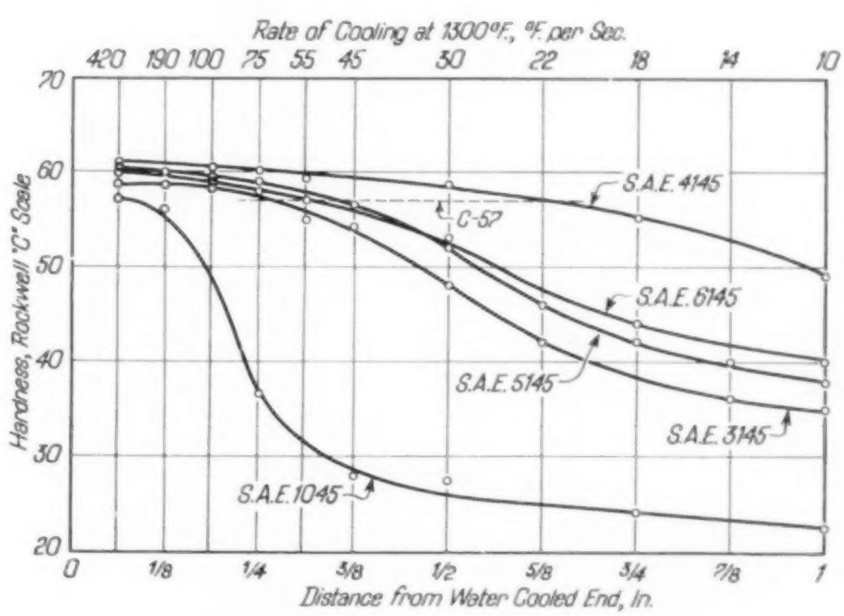
The truck gear is a carburized part so these steels would not be used. However, if we had an oil quenched transmission gear of this size and cooling rate it would be seen that none of the 0.45% carbon steels in the chart would measure up to our requirements of C-57 hardness, as quenched, though the 4145 steel would come pretty close, since it would harden to about C-55 at its 17° F. per sec. cooling rate.



Hardenability Curves (End-Quench Bars) of Five Steels Containing 0.40% Carbon

For a carburizing steel the picture is a little more complicated. As has been previously published, the hardenability will vary with the carbon content and consequently the hardenability will change somewhat with different carburizing compounds and different case depths. The best way to determine whether a steel is satisfactory is to carburize an end-quench test bar in the same manner and at the same temperature that the part in question will be treated. Then by choosing the distance from the water cooled end where the rate of cooling is the same as found for the location in question, the hardness is obtained at the same depth below the surface as for that of the part being compared. For the truck gear we are considering, we should measure the hardness on the end-cooled bar at a point $\frac{11}{16}$ in. from the water cooled end (for at that place the cooling rate is 17° F. per sec.) and 0.050 in. below the surface.

Of the steels we have tested, carburized S.A.E. 3115, 5115, 6115, or some compositions of 4615 would not harden at this point, whereas 4315, 4815, and some compositions of 4615 hardened satisfactorily.

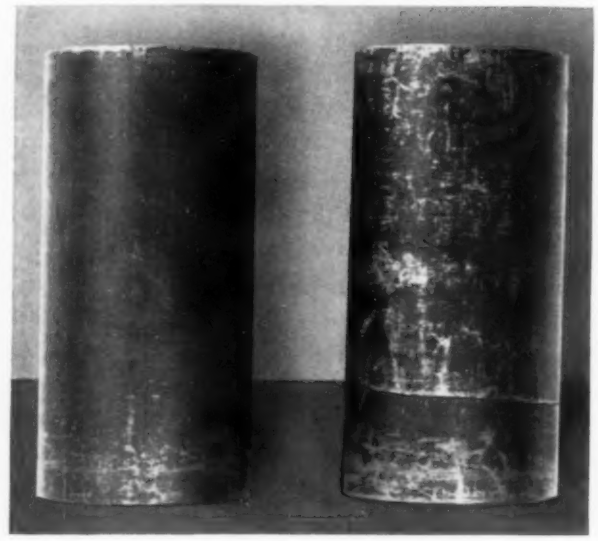


Hardenability Curves (End-Quench Bars) of Five Steels Containing 0.45% Carbon

It is important to notice the method and reasoning applied here because although it appears simple there have been several errors made in attempting to apply it. Professor Bruckner, of the University of Illinois, recently made a painstaking study of the hardenability of carburizing steels. (See University of Illinois *Bulletin*, vol. 37, No. 13, Nov. 21, 1939.) He is mistaken in applying the data from the test bar to the part in question, and writes as follows: "If any object such as a large gear or bearing were taken, carburized at 1700° F. and quenched in such a manner that the surface cooling rate was the same as the surface cooling rate for the Jominy bar at 2½ in. from

the water cooled end, then the hardness value obtained at various depths in the JOMINY bar should be the same at the same depth as for the gear or bearing." This is incorrect because the rate of cooling in the test bar at a given distance from the water cooled end is essentially the same at various depths beneath the surface, whereas with a quenched gear the rate of cooling varies widely from the surface to points beneath the surface.

It is not to be inferred that the only consideration in choosing steel for a part is the hardenability of the steel. Very commonly, however, the least expensive steel which has sufficient hardenability is chosen.



"L" Type Hardenability Test Bars Showing That Rather Slight Differences in Hardenability Make a Part Liable to Crack

Too Much Hardenability Undesirable

It is our belief that a steel may have too much hardenability for a given part. It is well known that in moderate sized parts steels like S.A.E. 3140 will crack when water quenched. In general, a slower rate of cooling such as an oil quench will prevent cracking — though there may be exceptions to this with certain shapes. Experience with parts which will crack when quenched in oil is not so common, but occasionally this occurs with small parts made of steel of high hardenability. Such cracking can usually be eliminated by cooling more slowly, as in air cooling.

These experiences lead us to believe that steels with excessive hardenability for the application should be avoided, since if they do not actually crack they will probably be in a highly stressed condition after quenching. This results in undue distortion as well as being generally undesirable.

As an example of a steel cracking under conditions in which a shallower hardening steel does not crack, the photograph above is presented. Two steels of about 1.00% carbon were machined into our "L" type hardenability test bar for shallow hardening steels. They were both heated to 1600° F. for 1 hr. and quenched in oil, then reheated 1 hr. to 1450° F. and cooled on our hardenability fixture. Two tests were run for each steel and it was found that both the deeper hardening steel test bars cracked and neither of the shallower hardening bars cracked. One of each of these is shown. The hardenability of these steels is 12/32 in. for the shallow and 14/32 in. for the deep hardening steel on our "L" bar, and by the Shepherd disk test No. 11 for the shallow and No. 12 for the deep hardening steels. The compositions of these steels were closely similar, as shown by the following analysis for the usual elements:

	SHALLOW	DEEP
Carbon	1.10%	1.10%
Manganese	0.29	0.25
Silicon	0.23	0.26
Sulphur	0.012	0.011
Phosphorus	0.015	0.018
Chromium	0.06	0.10

Oil Quenching the Sixth and Last Spline Shaft From a Furnace Load. All heat treatment is done vertically and out of contact with equipment or the other parts. Photograph courtesy Cincinnati Milling Machine Co.

Hot *and* Cold Heading

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THIS SUBJECT MATTER IS A PORTION OF that used for presentation to the Chicago Chapter ⊕ and is limited to the hot and cold heading of low and medium carbon engineering and structural steels, and will refer mainly to the materials which are headed. The materials which are used for heading tools will be discussed in a later installment.

Headed parts are grouped under the general engineering classification of fastening devices. The most common fastening devices are more specifically referred to as bolts, pins and rivets. The differentiation between bolts, pins and rivets is in the method of fastening although there is considerable overlapping; for instance, bolts are fastened by riveting as well as by threaded nuts.

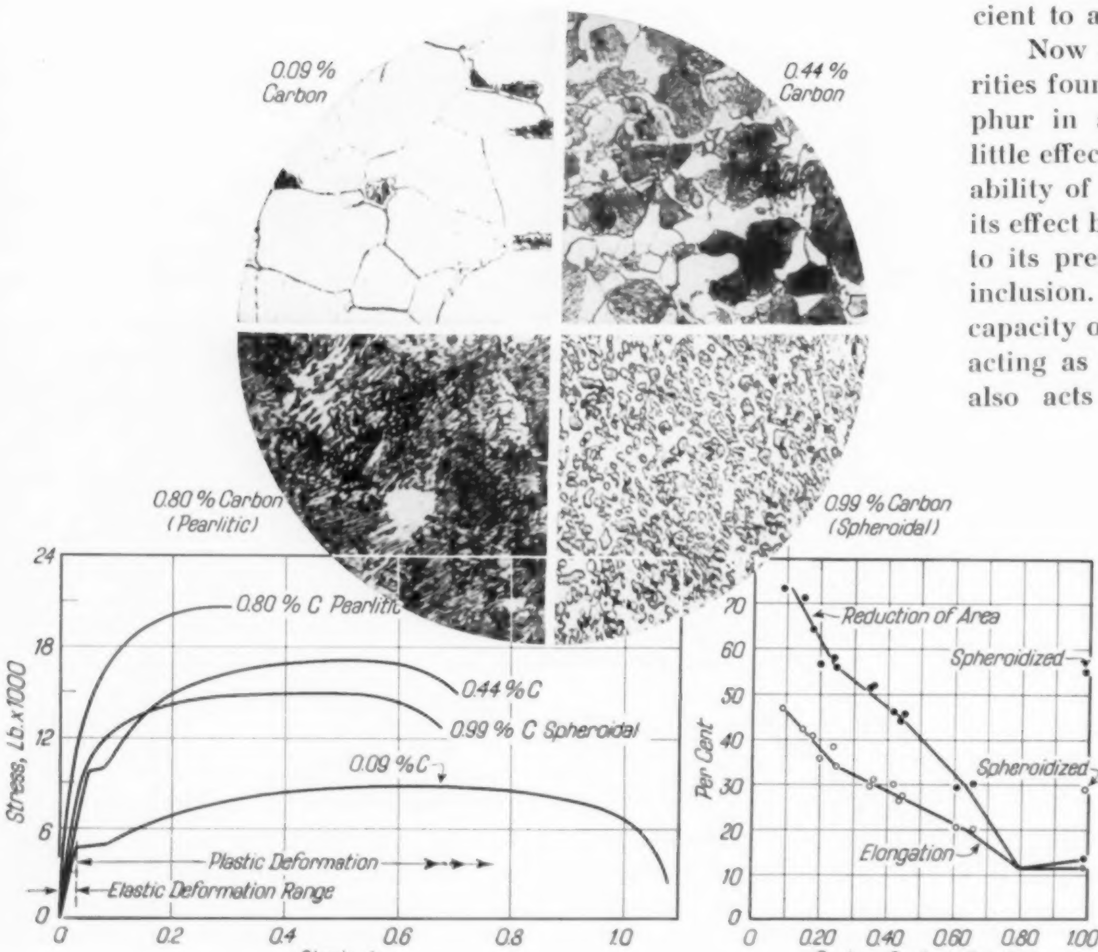
The decision as to whether a part is to be cold headed or hot headed is generally made with the metallurgical fact in mind that metal is more easily deformed as its temperature increases. It is a usual practice to draw the line between cold heading and hot heading on the basis of the diameter of the stock — that is, at about 1 in. It is also common practice to limit a cold-headed part to about 8 in. in length. These limitations are imposed for mechanical reasons, there being no theoretical basis for them.

The process of cold heading utilizes, in the worked material, its capacity for plastic flow. Plasticity is defined by JEFFRIES as "the quality by virtue of which a substance may undergo a permanent change in shape without rupture". An exact measure of the capacity for plastic flow in cold steel is very difficult to obtain, but a comparative measure may be obtained for various steels from the tensile test.

The plastic range of a material as shown by the tensile test is illustrated by the stress-strain curve for 0.09% carbon steel, reproduced in the first engraving on page 692. The elongation value, as measured by the change in the original gage length at the time of rupture, is considered a measure of the capacity for plastic flow, although it also includes the elastic deformation range, for the latter has a much smaller value in proportion. The greater the percentage of total elongation in the tension test, the greater the capacity of the steel for plastic flow. Another value obtained from the tensile test is also used to estimate cold workability, namely the reduction of area, a value obtained by comparing the original cross-section area with the final cross-section area after rupture.

It is said by some that neither the elongation nor the reduction of area can be used alone, but that the two must be considered together. Without entering into a detailed discussion of the difference of opinion which exists on the interpretation of the tensile diagram, it can be safely said that these values either singly or combined can be used to compare the plastic flow characteristics of one steel with another. However, the values themselves, as expressed in percentages, cannot be translated directly. For example, a 0.10% carbon steel will have an elongation of say 50% and a reduction of area of 75%, yet this steel is capable of being reduced in one dimension by cold compression at least 90%. Similarly, a 0.45% carbon steel giving an elongation value of 25% and a reduction of area of 45% can be reduced at least 70% before failure. There is no arithmetical relationship, but nevertheless the steel with the higher ductility (as measured by elongation and reduction of area) will be more suitable for cold heading.

Starting with more or less pure iron as a base point, consider the effect of added elements on the capacity for plastic flow. Carbon reduces this capacity to a marked extent — more so than any other element ordinarily contained in structural and alloy steels. This is clearly shown when the ductility in tension is plotted against the carbon content of annealed steels. In the first-mentioned figure the elongations and



Estimation of Cold Workability by Carbon Content and Ductility (Elongation and Reduction of Area in the Tensile Test) Must Be Correlated With Microstructure

reductions of area are used as a measure of the capacities for plastic flow.

The effect of carbon becomes clearer if we consider iron containing carbon as consisting of two microstructural elements, ferrite and pearlite. Ferrite has a high degree of workability and pearlite has a low capacity for cold working. The first group picture also illustrates the microstructure of four steels ranging from 0.09 to 0.80% carbon with an increasing amount of pearlite, the relatively unworkable microstructural element. It also shows another type of microstructure consisting of ferrite and carbide spheroids. From the stress-strain curves alongside it can be deduced that the steels, ranged in the order of their workability, would be: 0.09, 0.44, 0.99 and 0.80% carbon. The workability of the 0.99% carbon seems out of line, considering it by carbon content alone, but considering it from the viewpoint of mechanical arrangement it seems to take a reasonable position. This illustrates that carbon content considered on a chemical basis alone is insufficient to appraise cold workability.

Now as to the effect of the impurities found in commercial steel: Sulphur in amounts up to 0.050% has little effect; over 0.050% it reduces the ability of the steel to be cold worked, its effect being chiefly mechanical, due to its presence as a relatively brittle inclusion. Phosphorus reduces the capacity of the steel for cold working, acting as a ferrite hardener. Silicon also acts as a ferrite hardener, although its effect in reducing workability is not quite so high.

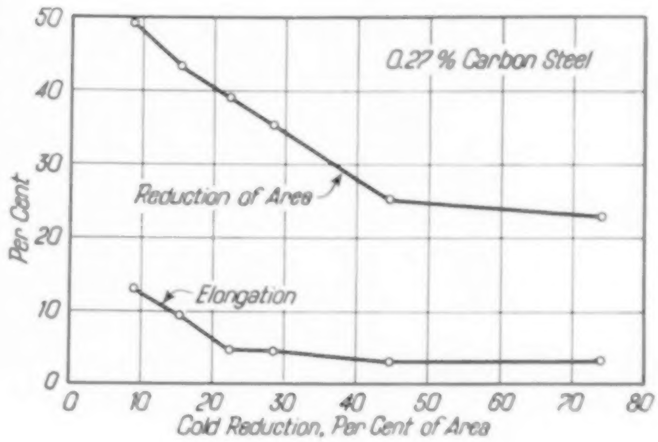
Alloying elements such as manganese, nickel, chromium, molybdenum, and vanadium also reduce the capacity for cold working. Their effect, in the absence of a larger percentage of carbon, is to reduce the ductility of the ferrite constituent. Their probable order in influencing the ferrite portion of the microstructure is in this order: Manganese, nickel, molybdenum, vanadium and chromium. In order to offset their effect when considerable pearlite areas are present, the carbide plates are transformed to the spheroidal form by appropriate heat treatments.

Prior cold working on the material to be cold headed reduces its ability to be further cold worked. Its effect is illustrated in Fig. 2. This figure assumes that the elongation and reduction of area values are a measure of the cold working capacity.

To turn to hot heading, in this operation the material in process acts more like a liquid than a solid. It has an almost infinite capacity for hot working within a range bounded by its upper critical range and its burning range. This is approximately the forging temperature range, and is illustrated in Fig. 3.

Carbon has its effect in increasing the difficulty of hot forming but in the light of Fig. 3 we can consider its effect as mainly in reducing the forging range.

Fig. 2 — Diagram (Due to P. Goerens) Showing How the Elongation and Reduction of Area in the Tensile Test — and Inferentially the Capacity for Further Cold Work — Is Reduced by Prior Cold Work, Especially in Amounts up to About 50%



As to the effect on hot heading of the impurities found in engineering structural steels — phosphorus in the amounts usually present has little effect. As to sulphur, although its presence is not generally desirable in steel to be hot worked, steels containing up to 0.30% can be headed better by the hot process than in the cold. While the usual alloying elements, in the amounts present in heading materials, do not materially affect the ability of the steel to be hot worked, they slightly increase the resistance of the steel to free flow.

Returning now to cold heading, we may say that in distinction to hot heading practice there is a clearly established limit to cold work that can be imposed on steel by its carbon content, the alloying elements and prior cold work. The commercial heading practice must be designed to take these important facts into account.

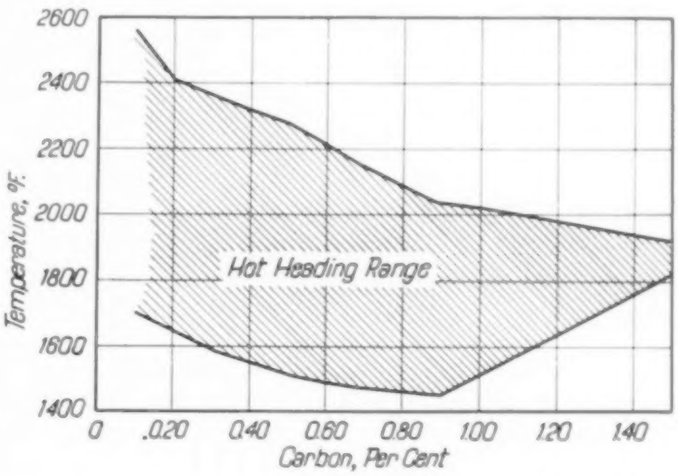
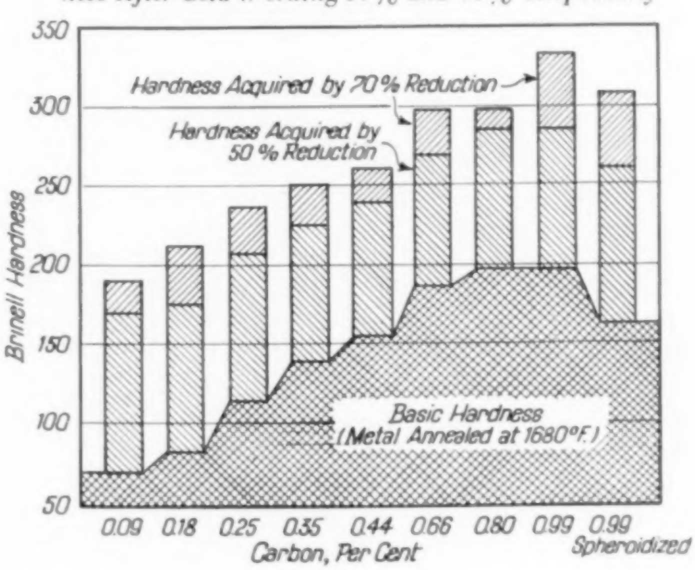


Fig. 3 — According to W. H. Hatfield, the Hot Heading Range Is Limited on the Top by Danger of Burning the Steel; on the Bottom by the Transformation of Austenite

Fig. 4 — Illustrates the Increase in Brinell Hardness After Cold Working 50% and 70% Respectively



After the parts are cold headed, it is often necessary to heat treat them so as to prepare them for application, as they have become relatively hard and lacking in some instances the necessary qualities for the intended use. But first we will briefly cover what happens to the steel in the cold heading process as this has a great deal to do with the heat treatment.

It is well known that cold working hardens steel. See Fig. 4. The exact mechanism of this hardening action has not been clearly explained — or at least the various explanations have not been generally agreed upon. This was well shown by Dr. Hoyt in his recent Campbell Memorial Lecture (page 659). It was stated by Ewing and Rosenhain that plastic deformation of metals under stress is accompanied by a process of direct slipping along gliding planes or surfaces of the numerous crystals contained in the metallic mass. There is good experimental and visual evidence of this, and for the resulting increase in indentation hardness which seems to accompany it. While no one doubts that plastic flow is accompanied by slip, various theories have been advanced to explain this kind of hardening.

One, associated with Beilby's theory, is that a vitreous, amorphous (non-crystalline) material is produced on the slip planes. This theory

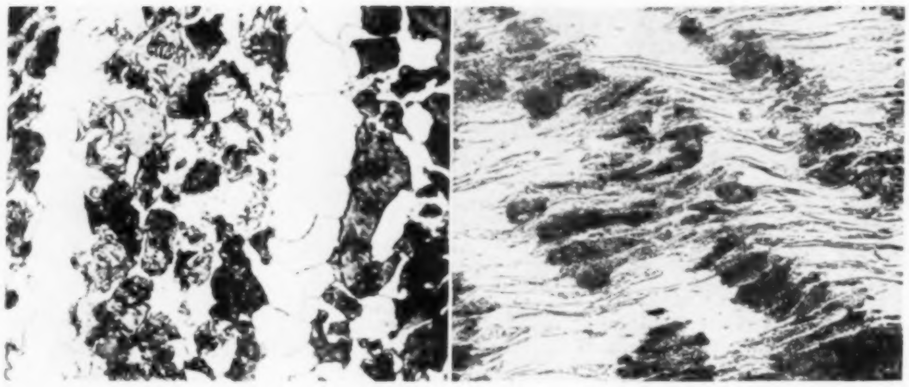


Fig. 5 — 0.35% Carbon Steel (Banded Microstructure) in Unworked Condition and After 70% Compression in One Dimension, at 300 Diameters

postulates that as slippage takes place a layer of solid takes on the mobility of a liquid and when slipping ceases a vitreous, amorphous material is formed.

TAMMANN says that hardening by cold straining is produced as a result of the formation by twinning of an increasing number of crystalline lamellae, without any destruction of the true crystalline arrangement. According to this view, a worked metal differs from an unworked in having its crystals definitely oriented owing to the development of cleavage lamellae and twinning.

It is further said by CHAPPEL that when metals are subjected to stress the molecular or crystal units at the cleavage or gliding planes are brought into a state of high tension. This corresponds with the condition which exists until the stress reaches that of the elastic limit of the material. When, by further deformation along one of these planes, the tension becomes greater than the molecular cohesion the molecular continuity is broken and deformation along this plane becomes permanent. This would then constitute exceedingly fine twin lamellae. He then goes on to say that further grinding together of these surfaces produces a debris which retains a crystalline nature.

The authorities apparently disagree, but at any rate there is no doubt that plastic deforma-

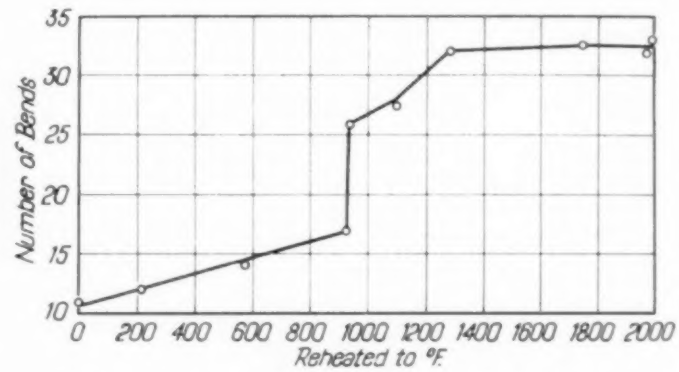


Fig. 7 — Illustrating the Effect of Reheating on the Ability of Cold-Worked Low Carbon Steel to Resist Rupture on Reversed Bending. (Goerens)

tion results in a disturbance of the molecular arrangement with possibly the formation of at least a subcrystalline material which may be called amorphous-behaving (for lack of a better term) which would be in a state of high molecular tension. Microscopically the effect of deformation on a banded medium carbon steel is illustrated in Fig. 5. It will be noticed that both the ferrite grains and the pearlite areas are deformed. Should the cold work applied be too great the material will rupture; these ruptures, of course, cannot be restored by heat treatment.

If the material which has been headed had originally considerable ductility (cold working capacity) which has not been used up by too

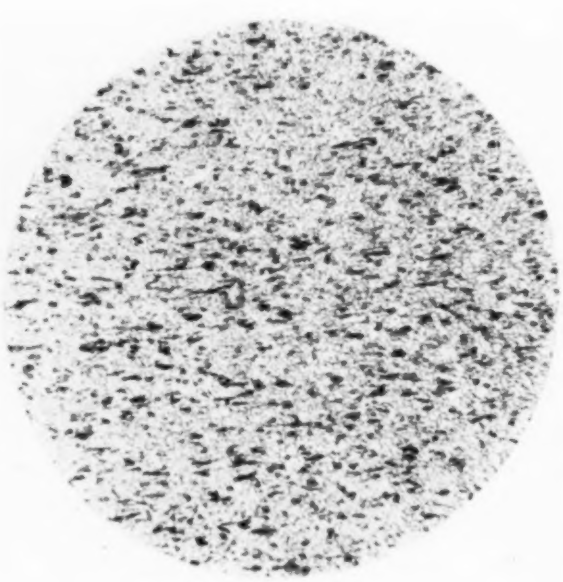


Fig. 6 — Microstructure of Cold-Worked Low Carbon Steel, Reheated Slowly Through the 900 to 1000° F. Temperature Range. Recrystallization of the ferrite has been complete. Etched with nital; magnified 100 diameters

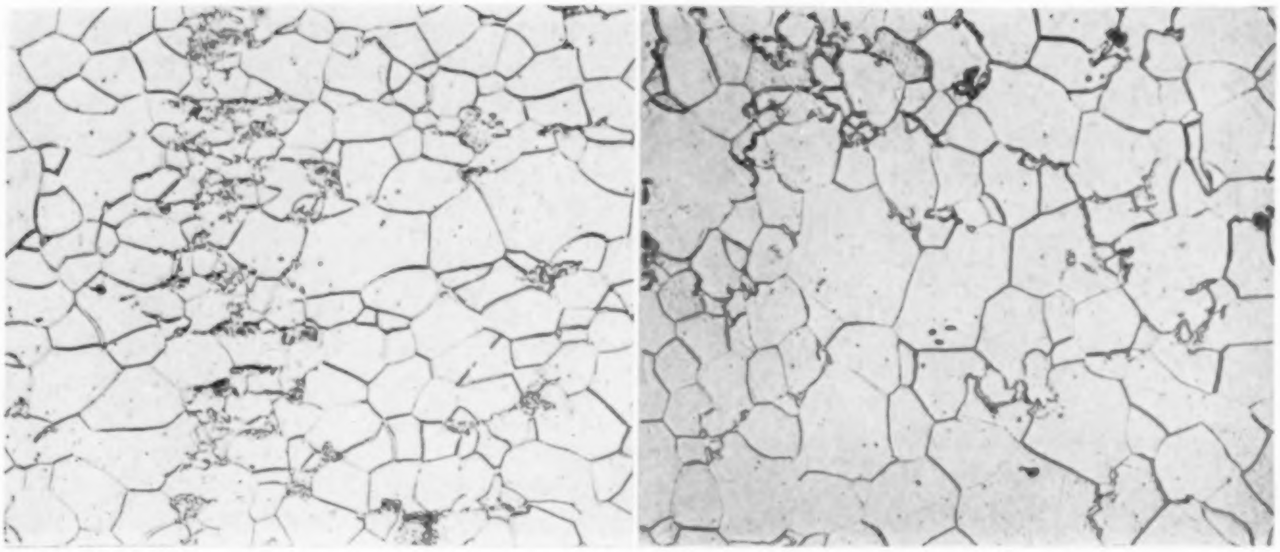


Fig. 8 — Deformed Pearlite Areas in Cold-Worked 0.09% Carbon Steel Retain Their General Shape Until the Steel Passes Through the Critical Temperature. After heating to 1300° F. (below A_1) as shown at left, the broken-up cementite has spheroidized, but it goes into solution before reaching 1400° F. and reappears on cooling as intergranular patches of pearlite. Etched with nital; magnified 300 diameters

severe deformation, no heat treatment of the headed part may be necessary. For example, many bolts made from S.A.E. 1010, 1015, or 1020 steel are used in the "as headed" condition. Bolts made on a relatively new machine are completed — that is, headed, trimmed and threaded — from S.A.E. 1035 steel and are still ductile enough to be used without any heat treatment. As a matter of fact, "as headed" low carbon steel bolts have a desirable feature, namely, a high yield point and a higher tensile strength than could be obtained by heat treatment. Low carbon steel rivets, from which further cold working capacity is required for cold riveting or squeezing, are heat treated.

It is advisable at this point to discuss the theoretical considerations and mechanism of the restoration of the original ductility of steel which has been cold worked.

A number of investigations have been made on the recrystallization of strained low carbon steel. This takes place at a relatively low temperature; the more severe the cold work the lower will be the recrystallizing temperature. This type of recrystallization should be clearly distinguished from that which takes place on passing through the critical transformation temperature, since as shown in Fig. 6 it may begin in cold-worked steel at about 925° F. — far below the transformation of ferrite into austenite. It will be noted that the ferrite grains are exceedingly fine at their inception.

Another indication of recrystallization is shown in Fig. 7. A large increase in the ability of a cold-worked low carbon steel to resist rupture by reversed bending occurs at about 950° F.

Examination at higher temperatures (Fig. 8) shows that the pearlite areas remain distorted until a temperature of about 1400° F. is reached, although there is no reason to doubt that the ferrite in the pearlite lamellae recrystallized as soon as the ferrite excess constituent.

If we accept the amorphous cement theory, then we must assume that the non-crystalline ferrite on heating to 925° F. becomes crystalline

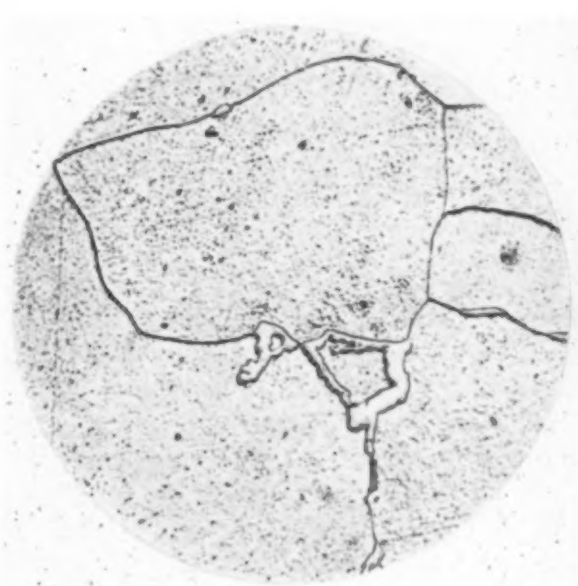
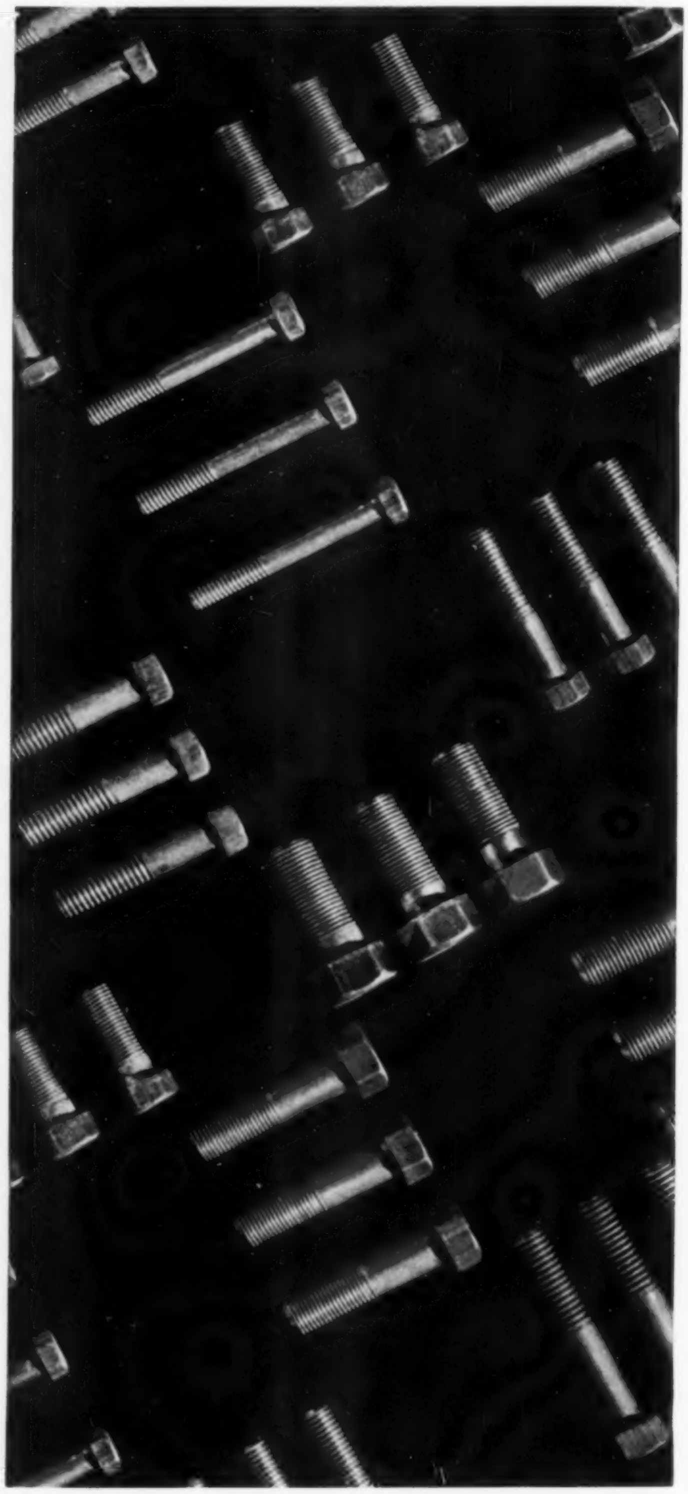


Fig. 9 — Carbide Segregated at the Grain Boundary of a Low Carbon Steel, After Cold Working and Reheating. Etched with nital; magnified 1000 diameters

again. According to the crystalline lamellae theory, there is a free re-orientation of the crystals at that temperature.

A phenomenon requiring some consideration occurs in low carbon steels. This is an abnormal grain growth taking place at temperatures from about 1290 to 1600° F. This occurs only where a certain critical straining takes place, where the stress has been about 33,000 to 40,000 psi. Crystals may grow to a size so that one of them would occupy the entire area of one of the micrographs in Fig. 8. The phenomenon is not evident in steels containing more than 0.12% carbon, yet it is unfortunate that it does occur in steels which have the greatest capacity for cold work. To be absolutely sure that full ductility is restored to a carbon steel of less than 0.12% carbon and to avoid loss of strength due to abnormal grain growth or grain boundary carbides, it must be heated to a temperature considerably above its upper critical range.



Another condition occurs in cold-worked and reheated low carbon steel — namely, carbide segregation at the grain boundaries. See Fig. 9 on page 695. This condition is due to the large solubility of carbon in ferrite containing a high oxygen content. The condition, therefore, is related to the melting and refining practice. Most of the low carbon steels prepared for cold working consist of rimmed steel — that is, "unkilled" or partially deoxidized steel. It is generally stated that rimmed steel has superior cold forming qualities. This statement when further analyzed means that the ferrite of rimmed steel is low in manganese, silicon and aluminum, and is therefore more plastic due to the absence of these ferrite hardeners. However, if this low carbon steel contains carbides segregated in the grain boundaries, it is exceedingly brittle. This condition can be corrected in the same manner as critical grain growth — namely, by reheating to about 1700° F.

Considering the foregoing from a practical standpoint in the cold handling of bolts and rivets, certain conclusions can be drawn and applied:

1. The most easily cold-worked steel is low carbon steel containing less than 0.12% carbon. It has certain disadvantages; namely, that it is subject to excessive grain growth after critical strain conditions when reheated for restoration of cold working capacity. It is also subject to carbide grain boundary segregation. In practice rivets made from this material are cold pressed or riveted without annealing. If hot riveted they are heated to a temperature above 1650° F.

2. Low carbon steel ranging from 0.15 to 0.25% carbon is the most commonly used both for bolts and rivets. For

cold riveting the rivets are annealed at 1550° F. Bolts are process annealed at 950 to 1100° F. in order to retain the high yield strength given by cold working.

3. Carbon steels ranging from 0.25 to 0.45% are used where maximum physical properties are desired by subsequent heat treatment. Or they may be process annealed, or used as headed, where the heading practice has been designed to bring about a minimum of hardening during the cold work.

To return to hot heading, hot-headed parts can be used in the hot-headed condition as they are not work hardened. Although they may be subjected to large distortion in hot working, they undergo a continuous recrystallization, for all working occurs above the critical transformation range.

Approximate Composition of Cold-Headed Materials

Type	C	Mn	Si	Cr	V	Mo	Ni
Carbon steels	0.08	0.20	0.05				
	0.15	0.45	0.05				
	0.18	0.75	0.05				
	0.20	0.60	0.05				
	0.35	0.80	0.15				
	0.40	0.80	0.15				
Manganese	0.35	1.35	0.20				
	0.35	1.65	0.20				
Chromium	0.38	0.60	0.20				
Chromium-vanadium	0.38	0.65	0.20	0.90	0.15		
Chromium-molybdenum	0.38	0.70	0.20	0.90		0.20	
Molybdenum	0.40	0.80	0.20			0.25	
Chromium-nickel	0.38	0.70	0.20	0.60			1.25
Nickel	0.35	0.70	0.20				3.25
Nickel-molybdenum	0.40	0.75	0.20			0.15	1.20

Study of Flow Lines Is Useful

One of the most practical ways to determine whether the cold heading or hot heading practice is correct is to study the flow lines by deep etching sections cut through the headed parts. This is a well-known practice in forge shops, and need not be discussed in this article.

The materials which are commonly cold headed have been referred to earlier, and are now shown in tabular form on this page. They are used in the form of cold-drawn wire either obtained from the steel mill or drawn at the header from hot-rolled wire. The reason for using a cold-drawn product is to hold the close tolerance — say ±0.001 in. — which is necessary for die work. It must be borne in mind that body tolerances on bolts and rivets are held to 0.004 in. or less total diameter tolerance.

A finish on the wire which minimizes friction against die walls is produced by the use of grease, soap, and the like in the cold drawing operation, whether the material is drawn at the wire mill or at the header.

In order to provide the maximum capacity for cold work it is necessary to anneal steels which, due to their analysis, have a minimum initial capacity for cold work such as the medium carbon and medium carbon alloy steels. The steels are either annealed to produce a ferrite-pearlite structure or a ferrite-spheroidized structure, as shown in Fig. 10.

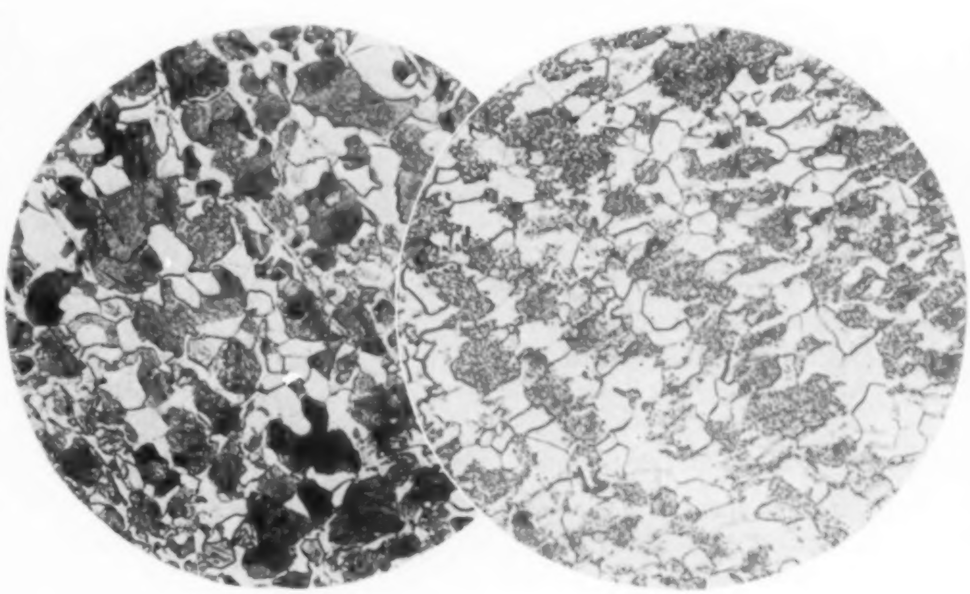


Fig. 10 — Steel With 0.44% Carbon, Normalized at 1680° F., Is Shown at Upper Left. Other structure — also designed to improve workability of the steel — is after spheroidizing at 1300° F. Magnified 300 diameters, nital etched

Deep Drawing Tests *for* Sheet Metal*

By H. W. SWIFT
Professor of Engineering
Sheffield University
Sheffield, England

VARIOUS TESTS FOR THE DEEP DRAWING qualities of sheet metal have been proposed, but as the result of use and critical study it is amply certain that each is satisfactory under certain conditions and unsatisfactory under others. From the standpoint of the material the primary effect of a deep drawing operation is to produce strain (plastic movement) and the essential requirement of the material is the ability to withstand and transmit this strain. The strain involved is, of course, a compound strain determined not only by the form of punch and die, but also in some measure by the stress-strain relationships of the material under compound strain. An elementary view of these strains may be had by ruling circles and diameters on a round blank and measuring the changes in dimensions after each of the three-stage operations required to produce a parabolic reflector. Severe "bending strains" occur locally over the die in all stages. Close to the center of the original blank the material is stretched both in the radial and in the circumferential (hoop) directions — a type of plastic flow that may be called "stretching". On the other hand, material further from the center is compressed in the hoop direction while it is stretched radially; this may be called a "drawing strain". It is to be noted that the stretching process necessarily involves a thinning of the sheet, while the "drawing strain" may and frequently does produce a thickening.

The three types of action — bending, stretching, and drawing — occur together in most press operations, but in varying amounts. "Stretching" may occur without "drawing" in certain shallow pressing operations, but "drawing" does not occur without "stretching" under any normal conditions, and when material fails during pressing it almost invariably fails in a region subject to stretching as distinct from drawing.

This fact has naturally led to the conception that the most suitable material for drawing purposes is one which can be subjected to most stretching without fracture. This has led in turn to the use as a criterion of drawing quality, of either the elongation measured in a tensile test or the depth of penetration in a cupping test. As ordinarily used, the cupping test can distinguish between good and bad material, but does not separate those that are just suitable from those that are just unsuitable for an exacting operation. Reproducibility in customers' and steel manufacturers' laboratories can be achieved if adequate precautions are carefully enforced.

The unpopularity of the cupping test is probably due to the fact that it has been used as a criterion of merit in connection with press operations which are predominantly of the drawing, as distinct from the stretching, type.

The forms of test hitherto proposed which can fairly claim to measure the intrinsic "drawing" quality of a material are of two types. In one the test consists in the production of a simple drawn pressing, while in the other a wedge-shaped specimen is pulled in such a way as to produce the drawing effect.

The more directly simulative form of test consists essentially in drawing a circular blank through a die of given diameter; the drawing property of the material is measured either by the greatest depth of cup or (more conveniently) by the greatest diameter of blank which can be successfully drawn. This test has been studied extensively and test machines are available from instrument builders. Some authorities have suggested a two-stage *(Turn to p. 700)*

* Abstract of an article in *Journal* of the British Institution of Automobile Engineers, May 1940, pages 361 to 432.

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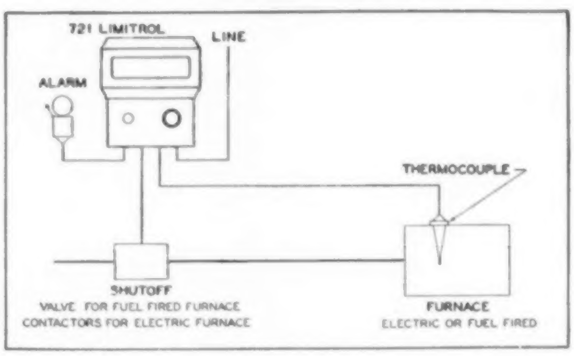
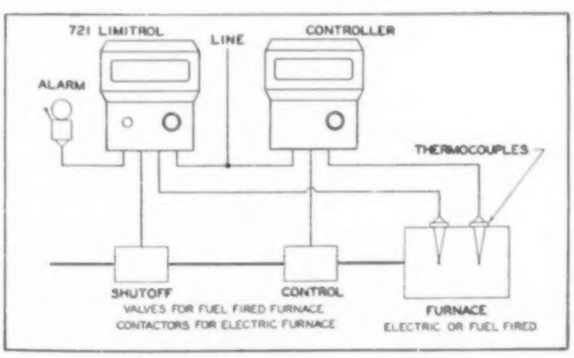


Operating Diagram showing use of Limitrol only.



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Deep Drawing

(Continued from page 698)

cup drawing test as being more discriminating — especially for aluminum — than a single draw.

The experimental work described in the present paper was undertaken primarily with the purpose of determining the suitability of the cylindrical cup pressing as a drawing test and of ascertaining proper conditions of test, but the investigation naturally touched on certain matters of a more general nature affecting the mechanism of the deep drawing process, and a detailed study of the paper is recommended for this purpose if for no other.

As an indication of some of the practical information that is contained, the subject of lubrication may be mentioned. Tests were made on 50 different lubricants when drawing cups of mild steel, brass and aluminum sheet. When arranged in the order of maximum load on the punch, the most effective lubricants were almost all distinguished by a solid constituent. Liquids — even those used for extra-pressure lubrication — were not suited to deep drawing under the conditions of this test (not involving any significant degree of ironing and a fairly low speed). Fine, crystalline graphite, low in impurities, ranks very high, either when used dry or mixed with tallow or soluble oil. Next in merit is a mixture of paraffine wax 50%, kerosene 25% and mineral oil 25%. Anhydrous sodium soap mixed with mineral oil also gave low punch pressures. Naphthalene dissolved in benzene gave good results on steel, fair on brass, but poor on aluminum because its particles are hard enough to score the softer metals.

The testing machine studied was a simple press having a punch of casehardened steel with a diameter of 2.000 in. and a flat working end with a radius of ¼ in. round the edge. The flat blank of metal (various materials in 0.036-in. sheets were tested) is centered and has no upper constraint, but slides under a cover to limit the "puckering". There is 1/16 in. clearance below the die. The die itself is a hardened steel ring, properly centered and supported, which determines the radius over which the sheet shall be bent and (by its inner diameter) the radial clearance to be permitted without ironing of the cylindrical pressing. The normal curvature of the ring (in section) is ¼-in. radius, and several inner diameters have been employed, varying from 2.067 in. to 2.094 in. for blanks 0.036 in. thick. Simple means were employed for an

autographic curve showing the relation between load on the punch and its movement during the test.

Early in the experimental work it was established that the maximum blank diameter which can be drawn successfully is a sensitive and consistent function of the drawing qualities of a metal. A series of tests at a slow speed of pressing showed that six mild steel blanks, 4.10 in. diameter, all drew successfully, while six blanks, 4.15 in. diameter, all broke at approximately the same stage of the draw. Of six blanks, 4.125 in. diameter, four failed and two drew successfully. This order of consistency was revealed throughout the testing work on all three metals when the conditions of drawing were kept constant.

In this connection it should be mentioned that all blanks were machined on the outer diameter before testing and were accurately centered in the die by means of adaptor rings; neglect to observe either of these precautions led to inconsistent results.

In cases where the drawing test is regarded as a proof test it is only necessary, of course, to demonstrate that a blank of a particular specified diameter will draw successfully. But where it is required to ascertain the actual value of the maximum permissible blank diameter more than one test is necessary.

Other experimental results justify certain proposals regarding the conditions of test:

1. In order to insure accuracy in dimensions and absence of burrs, the test blank should be machined on its outer edge.

2. In order to minimize the effects of drawing speed and parasitic friction, graphite lubrication should be employed.

3. Fixed blank-holder clearances are not readily adaptable to different thicknesses of blank and for commercial testing a fluid blank-holder would probably be more convenient.

4. Sufficient radial clearance should be provided between punch and die to prevent ironing except during the final stage of pressing. This would afford means for judging the thickening tendency of the material and the geometrical perfection of the finished cup.

5. In order to minimize friction the die profile should be provided with as generous a curvature as possible without risk of puckering.

6. In order to minimize the effect of any small irregularities and to leave clear evidence of the surface condition of the pressing, a generous curvature should be provided on the punch.

7. A 2-in. punch is large enough to minimize the effects of tolerances in workmanship and technique.

Personals

L. R. Kells, formerly chief engineer of Salem Engineering Co., has been placed in charge of the furnace department by Wellman Engineering Co., Cleveland.

C. C. Hermann has been appointed chief engineer of the Claude B. Schneible Co., Chicago.

Herbert G. Kamper is employed in the metallurgical department of the American Rolling Mill Co., Middletown, Ohio.

Gerhart Schindler is now employed by the Summerill Tubing Co., Bridgeport, Pa.

Returned to Youngstown Sheet & Tube Co., Youngstown, Ohio, as metallurgist: **Karl L. Fetters**, with Doctor of Science degree from Massachusetts Institute of Technology.

Installed as president of the American Society for Metals at the annual meeting held Oct. 23 during the National Metal Congress: **Oscar E. Harder**, assistant director, Battelle Memorial Institute; as vice-president, **Bradley Stoughton**, consulting engineer, Lehigh University; as secretary, **William H. Eisenman**; and as two new trustees, **Charles Y. Clayton**, professor of metallurgical engineering, Missouri School of Mines, and **E. L. Bartholomew**, metallurgist, United Shoe Machinery Corp.

A. W. Machlet, president, American Gas Furnace Co., received the Sauveur Achievement Award of the American Society for Metals in recognition of his pioneering metallurgical achievements.

Thomas J. Moore, Jr. is now first lieutenant in the Army Ordnance Department, Washington, D. C.

M. D. Bensley, sales representative in the Pittsburgh district for the past ten years, has been made assistant to **H. S. Bradley**, president of Shenango-Penn Mold Co. **H. H. Zollar** will take over Mr. Bensley's activities in Pittsburgh.

S. C. DuTot has been promoted to division manager in charge of all sales activities in the Birmingham, Pittsburgh, Cleveland and Detroit areas for Electro Metallurgical Sales Corp. **E. E. Wright** is district manager at Cleveland, and **F. H. Hanson** at Birmingham. **W. E. Remmers** has been appointed division manager in the Chicago office, and will be in charge of sales activities in the middle west, and **R. E. Brown** is division manager on the Pacific Coast, including all territory west of the Rocky Mountains.

John L. Schmeller, sales representative for the National Bronze & Aluminum Foundry Co., Cleveland, has been made vice-president in charge of sales.

Appointed Chicago district manager handling Aristoloy steels for Copperweld Steel Co.: **R. S. Clingan**, formerly with Republic Steel Corp.

Personals

A. W. Sykes, past chairman Chicago Chapter, has been called from his position as materials engineer, Bureau of Engineering, City of Chicago, to active duty with the U. S. Army and is now stationed with the Chemical Officer of the Sixth Corps Area with headquarters in Chicago.

Paul E. Nixon, formerly in the engineering department of the Caterpillar Tractor Co., Peoria, Ill., is now in the engineering checking department, Vultee Aircraft, Inc., Vultee Field, Calif.

James L. Laing, formerly with the Algoma Steel Corp., is now with the United Kingdom Technical Mission in Canada and the United States, as an examiner of materials at present stationed at Winnipeg, Man., Canada.

Honored by the American Welding Society: **William Spraragen**, technical secretary of the American Welding Society and editor of *The Welding Journal*, awarded the Samuel Wylie Miller Memorial Medal for conspicuous contributions to the art and science of welding; **H. J. French,** trustee, and **T. N. Armstrong, Jr.**, metallurgists with the International Nickel Co., Inc., awarded the Lincoln Gold Medal for the paper which contributed most to the year's development of welding.

Robert Crooks Stanley, chairman of the Board and president of the International Nickel Co. of Canada, Ltd., has been named first recipient of the Charles F. Rand Gold Medal of the American Institute of Mining and Metallurgical Engineers, for distinguished achievement in mining administration.

H. J. Barton has been appointed to the tool steel division, in the Southern California territory, for Allegheny Ludlum Steel Corp.

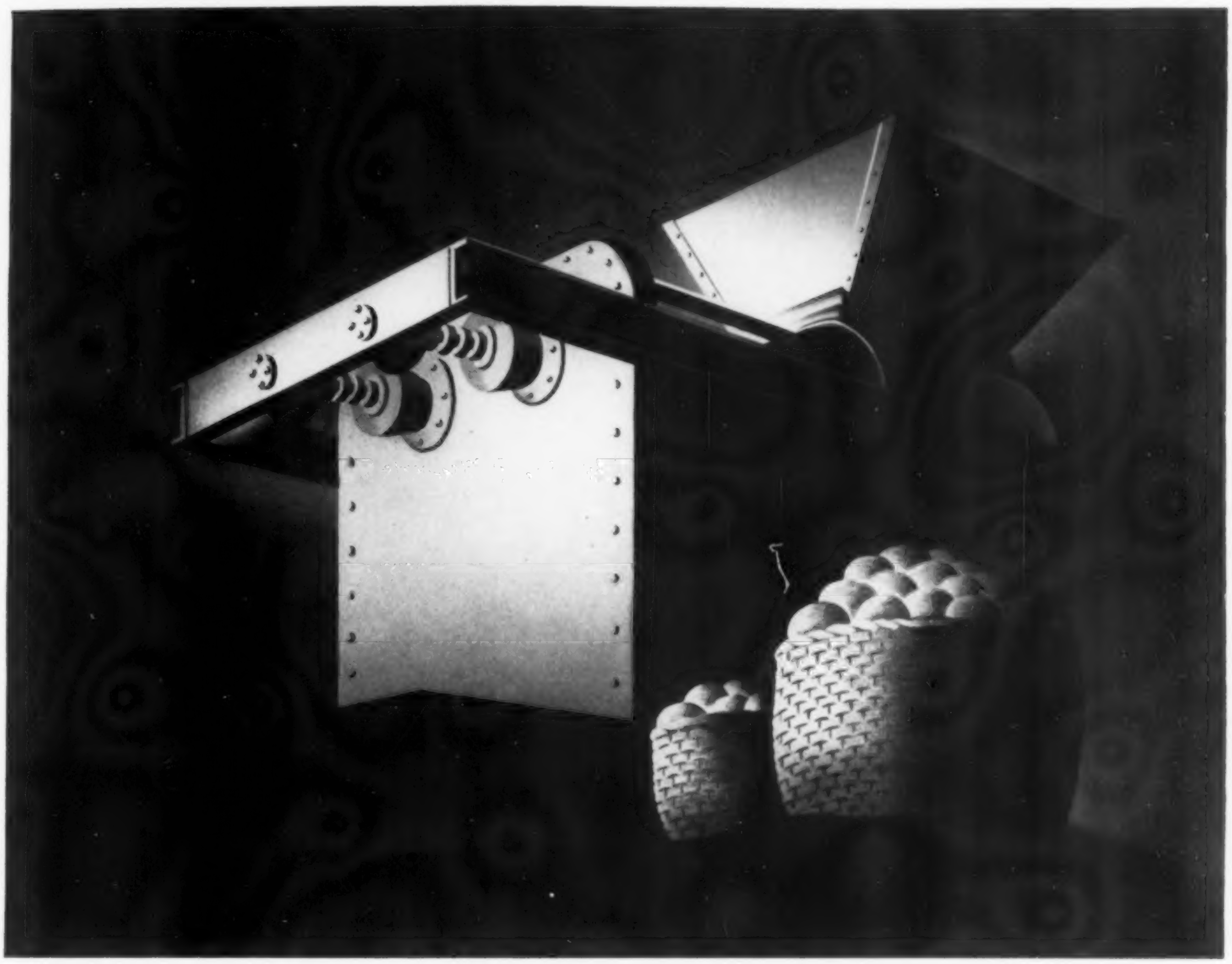
Promoted by Babcock & Wilcox Tube Co.: **Harvey Wilson,** formerly in charge of the Philadelphia sales office, now in charge of the New York office territory as district sales manager. **R. M. Lackner** has been transferred from the Detroit to the Philadelphia sales office, and **B. F. W. Seaburn** from the district sales office at Beaver Falls, Pa., to the Detroit office.

Max Bolotsky, M.S. in metallurgical engineering, Virginia Polytechnic Institute, is now a junior metallurgist at the Watertown Arsenal, Watertown, Mass.

Richard C. English is now in the industrial department, Marine Engine Scientific Section, Navy Yard, Philadelphia.

W. M. Woodward, formerly with Timken Roller Bearing Co., Canton, Ohio, is now with Rotary Electric Steel Co., Detroit.

Frank A. Thas, formerly of Chambon Corp., is now mechanical engineer with the Heald Machine Co., Worcester, Mass.



Personals

Maier Gittlen is serving one year's extended active duty as lieutenant with Company F of the 18th Engineers at Fort Logan, Colo.

John R. Post is a junior engineer for U. S. Gypsum Co., Southard, Okla.

John G. Sullivan has been transferred from product metallurgist at the Donora Works of American Steel & Wire Co. to works metallurgist at the Rankin Works in Pittsburgh.

Forrest S. Williams is now a technical apprentice at American Steel and Wire Co., Waukegan, Ill.

Eugene L. Olcott is in the metallurgy department of Bethlehem Steel Co., Lackawanna, N. Y.

Raymond H. Hilgenbrink, formerly in the tool design department, Caterpillar Tractor Co., has been appointed instructor of machine drafting at the David Ranken, Jr. School of Mechanical Trades, St. Louis, Mo.

Transferred by John A. Roebling's Sons Co.: **Fletcher Preston**, from the advertising department in Trenton, N. J., to the Chicago branch to sell cold-rolled strip steel and flat wire.

William A. Carlson, formerly with American Steel & Wire Co., Pittsburgh district, is now with the Superior Steel Corp., Carnegie, Pa.

E. J. Tompkins, formerly with Central Steel & Wire Co. in Chicago and Cincinnati, is now manager of the Chicago warehouse for Bliss & Laughlin, Inc.

A. R. Tresselt, Jr. has left Joseph E. Seagrams & Sons in Louisville, Ky., to work in the research laboratory of the Cummins Engine Co., Columbus, Ind.

Wilbur R. Varney, previously employed in the metallurgical department, Bethlehem Steel Co., Sparrows Point, Md., has taken a position as metallurgist for the Taylor-Wharton Iron and Steel Co. covering their plants at Easton, Pa., and High Bridge, N. J.

Roger O. Day, metallurgist, development laboratory, The Linde Air Products Co., Newark, N. J., and captain, 102nd Engineers, has been called into Federal service for the next year in connection with mobilization of the 27th Division, consisting of the New York National Guard troops.

H. Corwin Miller has left the Worthington Pump and Machinery Corp. to join the staff of the Greenfield Tap & Die Co. as foreman of the No. 2 plant, heat treating department.

W. F. Chubb, consulting metallurgist is now acting as independent consultant to Quyon Molybdenite Co., Ltd., Quyon, Que., Canada, for the production of ferromolybdenum, molybdic oxide, and calcium molybdate for the manufacture of steel and cast iron.

Electrode Coatings

(Continued from page 682) structural steel and machinery parts and are especially recommended for poor fit-up. The ductility of the metal deposited with these electrodes is not equal to that of Groups *A* and *B* and the welds would not pass rigid X-ray specifications. Electrodes of this group are used on straight polarity (electrode negative) direct current or on alternating current.

Group D. Heavily coated electrodes for downhand welding, particularly for fillet and lap joints including welds with one leg vertical. The layer of slag produced covers the entire deposit and results in smooth welds which blend nicely into the stock at the edges. Electrodes of this group may often be substituted for those of Group *A*, but the slag of Group *D* is troublesome in groove welding. The deposited metal is of good quality. Although the welds made with these electrodes are seldom subjected to X-ray examination, they would pass most codes. As a group, these electrodes operate on either polarity, direct current, or on alternating current, but some brands operate better on one or the other type of current.

With these four types of electrodes to choose from, the fabricator can readily weld all types of mild steel structures under any desired conditions. To obtain welds having sufficient strength is no longer a problem, for electrodes of all four types deposit metal which is stronger than mild steel. For maximum ductility, a choice of type must be made.

For use with the high strength low alloy steels the choice of electrodes is more limited than for carbon steel, but coated electrodes are available for welding most of them in the vertical as well as the downhand position. Coated electrodes are also available for welding many of the stainless steels. Corrosion resistance as well as mechanical properties of such welds is equal to that of the stock welded.

So far as the usual mechanical properties of weld metal are concerned, there is not much need for further improvement. Future developments will more likely be directed toward enhancement of the desirable operating characteristics of electrodes and the reduction of welding costs.

Notes on Contributors

The "end-cooling method" is the official name of the type of hardenability test developed in the General Motors Research Laboratory; the "Jominy test", however, is the colloquial name by which it is best known. But this new field of hardenability testing (see page 685 for a story of how it is used in practice) is not the only accomplishment of **Walter Jominy's** productive career. Before he became metallurgist in the Research Laboratories Division of General Motors, he did important work on scaling of steel during forging at University of Michigan's Department of Engineering Research (1923-31) and as research metallurgist for A. O. Smith Corp. (1931-34) — as witness his authoritative series of articles in the A.S.M. *Transactions* and elsewhere. His early career after getting a Master's in chemical engineering from University of Michigan included brief turns as metallographer for Studebaker; senior metallurgical inspector, U.S. Bureau of Aircraft Production; metallurgical engineer for Packard; and again at Studebaker in charge of chemical and metallurgical laboratories.

Talking before the Chicago Chapter A.S.M. last spring, **A. S. Jameson** chose a subject which is of wide interest but seldom reaches the printed page. This deficiency is now remedied with the publication of his talk on page 691. An Englishman, Mr. Jameson was educated at University of Sheffield and worked in the laboratories and steel making departments of Cammell Laird & Co., Ltd., and Henry Bessemer & Co., Ltd., before coming to the United States to take a position with the Crucible Steel Co., Midland, Pa., in 1925. Two years later he became associated with the International Harvester Co. and has been works metallurgist for the West Pullman plant since 1928.

A second contribution in this issue from the G.M. Research Laboratories comes from a somewhat younger member of the metallurgy department. He is **Howard L. Grange,** who graduated with a B.S. in metallurgical engineering from University of Wisconsin in 1938. He worked as a summer student in the Laboratories between his junior and senior years and apparently liked it and the lab. liked him, since he took a permanent position there after graduation.

Samuel L. Hoyt's Campbell Memorial Lecture presented last month in Cleveland heads a long list of metallurgical achievements which include development of cemented tungsten carbides (Carboloy) while metallurgical engineer at G.E.'s Lamp Department at Nela Park, 1919-31; work on heat resistant alloys, development of pressure vessels and steels for oil production equipment at A. O. Smith Corp., 1931-39; and production of a standard two-volume text on metallography while head of the department of metallography at University of Minnesota, 1913 to 1919. Dr. Hoyt is a graduate of Minnesota School of Mines and studied at Columbia (Ph.D. in 1914) and at Charlottenburg (Germany). Since 1939 he has been at Battelle Memorial Institute, where he acts as technical advisor in the planning and conduct of metallurgical research.

The article on arc welding electrodes on page 679 is not the first one that presents **Louis J. Larson** as a Metal Progress author, and an extended account of his career will be found in the December 1938 issue.

Samuel L. Hoyt

Walter E. Jominy

Alfred S. Jameson

Howard L. Grange

Powder Metallurgy

(Continued from page 668) hailed this as one of the great medical contributions to ameliorate the hazards of our industrial age.

Aluminum oxide films produced during the atomization of liquid aluminum constitute but 0.2% by weight of the powder thus made. For compaction, such powder is preferred to granulated and flake aluminum. That the oxide films in aluminum compacts permit proper adhesion and even diffusion of other alloy constituents during sintering was excellently illustrated in a prepared discussion by L. W. Kempf of the Aluminum Company's research organization. Some of his data are on page 668. (The figures come at a timely moment, and we hope that they will encourage publication of more items from the extensive researches carried on by others in this field.) Others at the meeting pointed out the extreme difficulty experienced in production when the plastic aluminum powder sticks to the walls and thus freezes the die. What lubricant to employ, whether "stearotex" admixed with the powder is most successful, or whether some radically different lubricants need to be used, was not established. Some of the newer ideas on friction, lubrication, and seizure presented by Hans Ernst and Otto Beeck at the Friction and Surface Finish Conference last June — and soon to be published — suggest a point of view which may aid in the solution of this problem.

In closing the meeting, Earle Patch expressed the sentiments of the audience in proposing another gathering of the same kind next year. That cooperation can lead to a more rapid advancement of the art with advantage to maker and user, few present would deny.

Campbell Lecture

(Starts on page 659) Amorphous metal occupied a position precisely similar to that of the other mythical constituent of metallurgy, beta iron, which, though its occurrence in high carbon steel was never proved (and hardness was never shown to be an outstanding characteristic), was held to be responsible for hardening on quenching. In both cases we have examples of the method of Aristotle. Amorphous metal, like beta iron, was simply endowed with those properties for whose explanation it was created, and then assumed to exist at the proper places. *That* is not the path of science.

While the scientific method gives us a sound procedure for developing the natural and physical sciences, there is as yet no substitute for inductive reasoning by which the man of genius reasons backwards from effect to cause, and on to basic principles or to the correct and appropriate postulate. This was so for the fields of heterogeneous equilibria and crystal structure and other branches of metallurgy which are nicely ordered, but is not yet true for plastic deformation in which field there is speculation, confusion, and disagreement.

If I were to theorize on plastic deformation I believe I would first secure an adequate picture of the macro, micro, and atomic mechanisms of the process. I would then make use of other recognized features of the metal lattice to secure a more complete understanding of its virgin condition and the ability of the crystal to distort permanently without rupture. We need not hesitate to accept the role of electrons providing the bonds between the metal ions, and to consider ions and electrons as the structural units. Furthermore there is good evidence that the valence electrons are more or less free to move and I would want to consider this characteristic when attempting to account for the typical plastic behavior and continuous bonding of metals as contrasted with the viscous behavior of fluids. Finally (and I believe this might well be a guiding principle to all of us) if it appeared that the theory of the metallic state had not progressed far enough for such applications, I would consider that further speculation should stop for the time being until a deeper insight into the problem was obtained.